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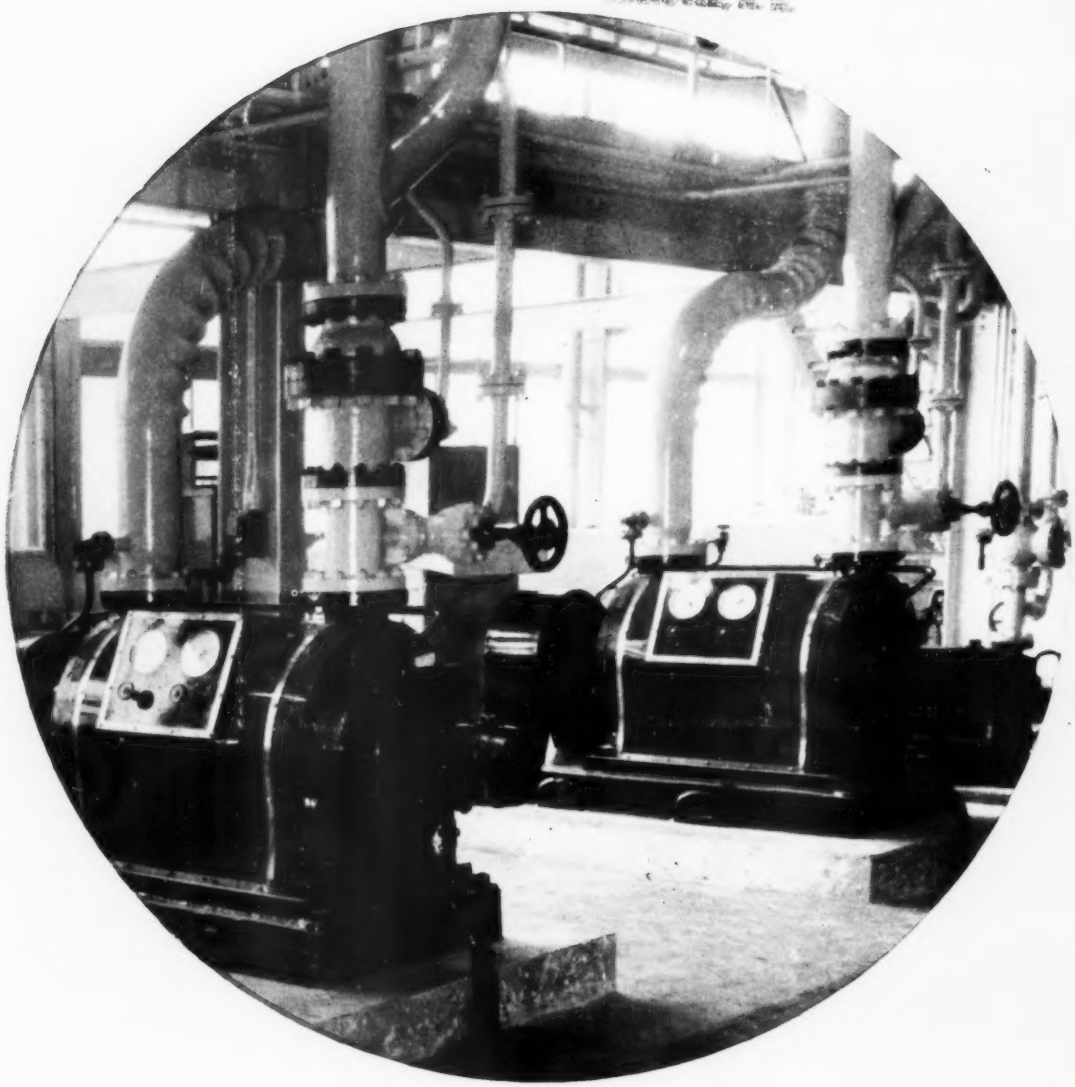

nps in atomic energy

rvey and articles pp68-73

Also in this issue

Plutonium as a fuel

The DCDR reactor

July 1961 monthly 3/6

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COVER PICTURE

Plurovane boiler feed pumps at Calder Hall nuclear power station.

Nuclear Power

REACTORS · MATERIALS · INSTRUMENTATION · PROCESSES · IRRADIATION

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New UK nuclear centre 58
Plans for a £1 million research centre at Oxford have been announced

Plutonium as a reactor fuel 59
Dr M. B. Waldron reviews some of the problems which have been exercising research workers all over the world for several years and comments on current progress

Burnout in liquid cooled reactors—2 64
Mr J. G. Collier concludes by comparing his suggested burnout mechanism with experimental results

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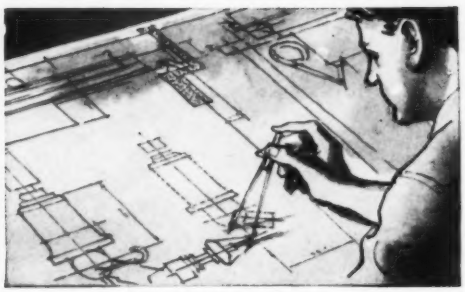
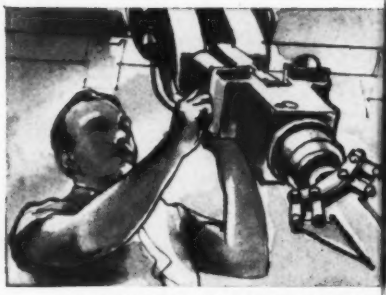
NE 8 For lifting and handling R-A materials weighing up to 7 lbs. The equipment has power driven side-swing movements

Consultation at the early stage



Preparing the basic plan



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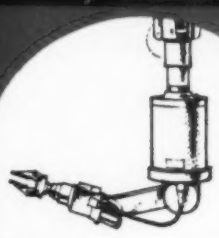

M300 The versatile unit with a lifting capacity from a few ounces up to 750 lb

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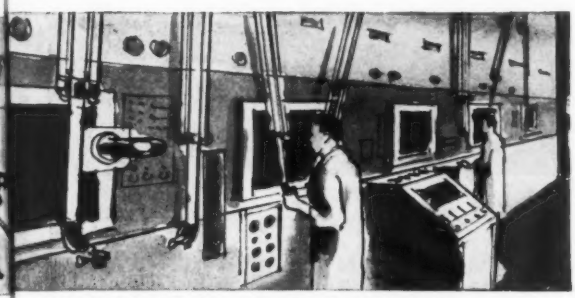

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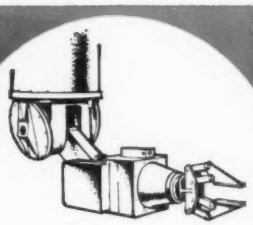
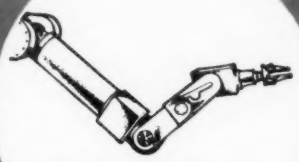
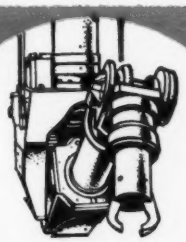


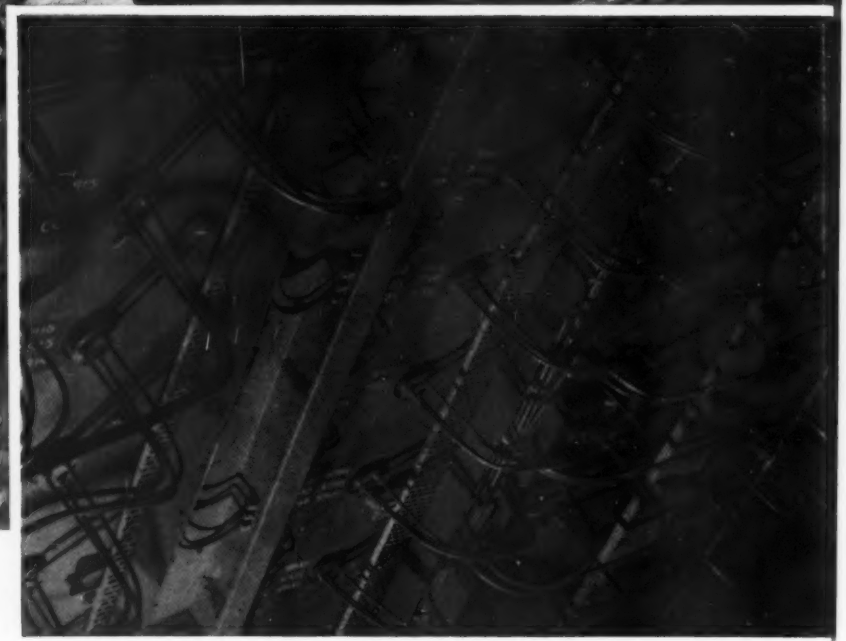
M500 Basically similar to M300 Handles up to 2,000 lb with a fine degree of control



M550 Offers wide versatility in heavy load applications, e.g., 100 lb cantilevered eighteen feet



M700 Heavyweight unit with a rigid hook for lifting loads up to 5,000 lb



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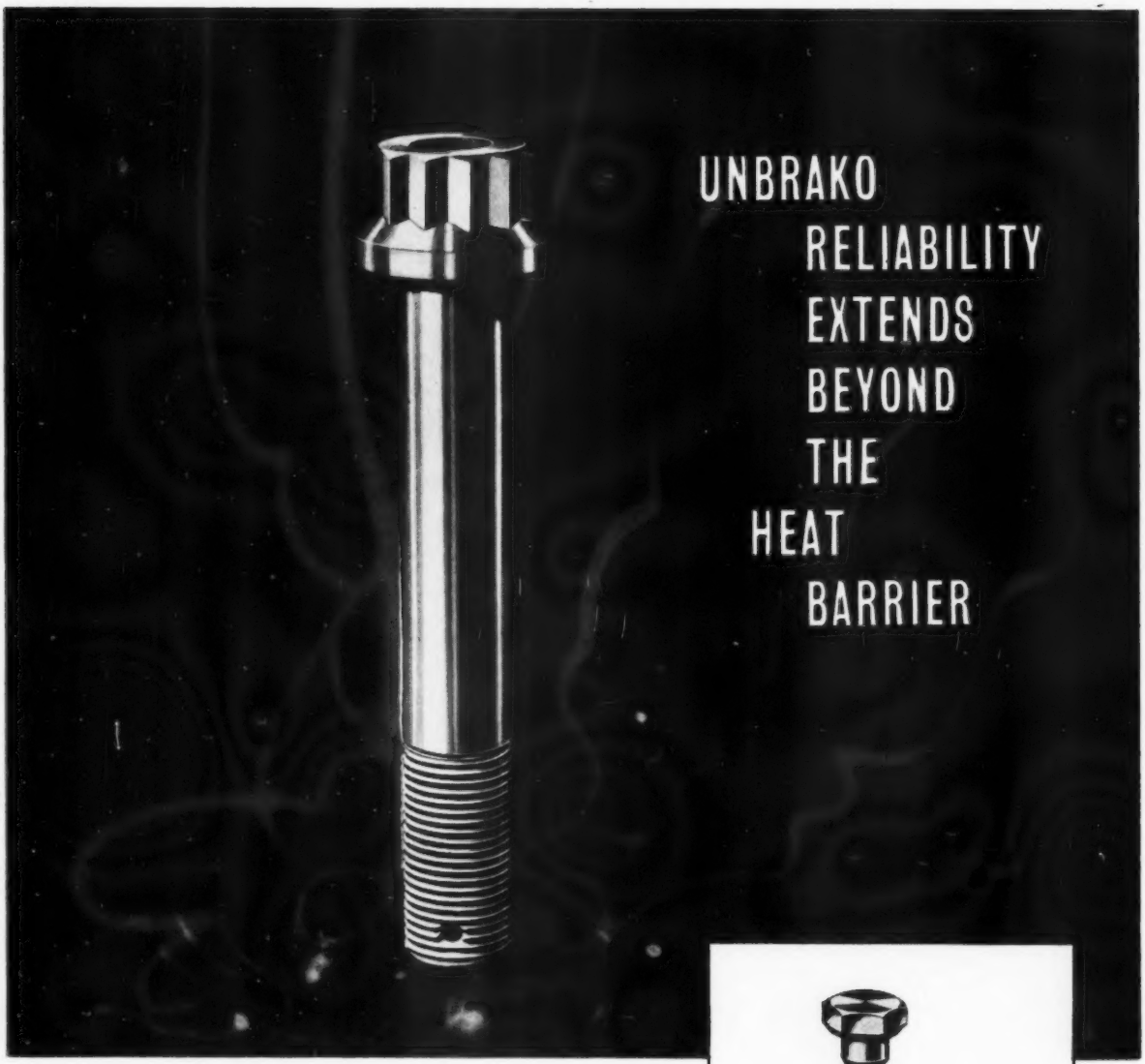

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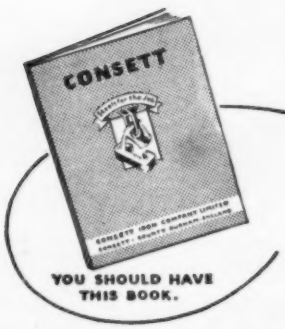

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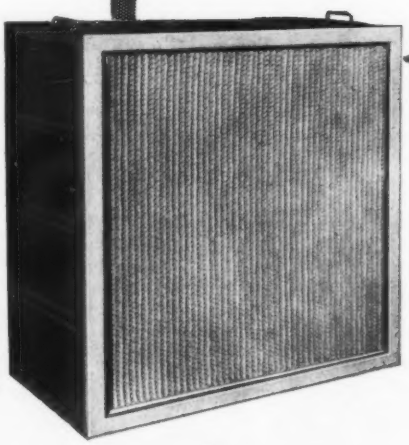

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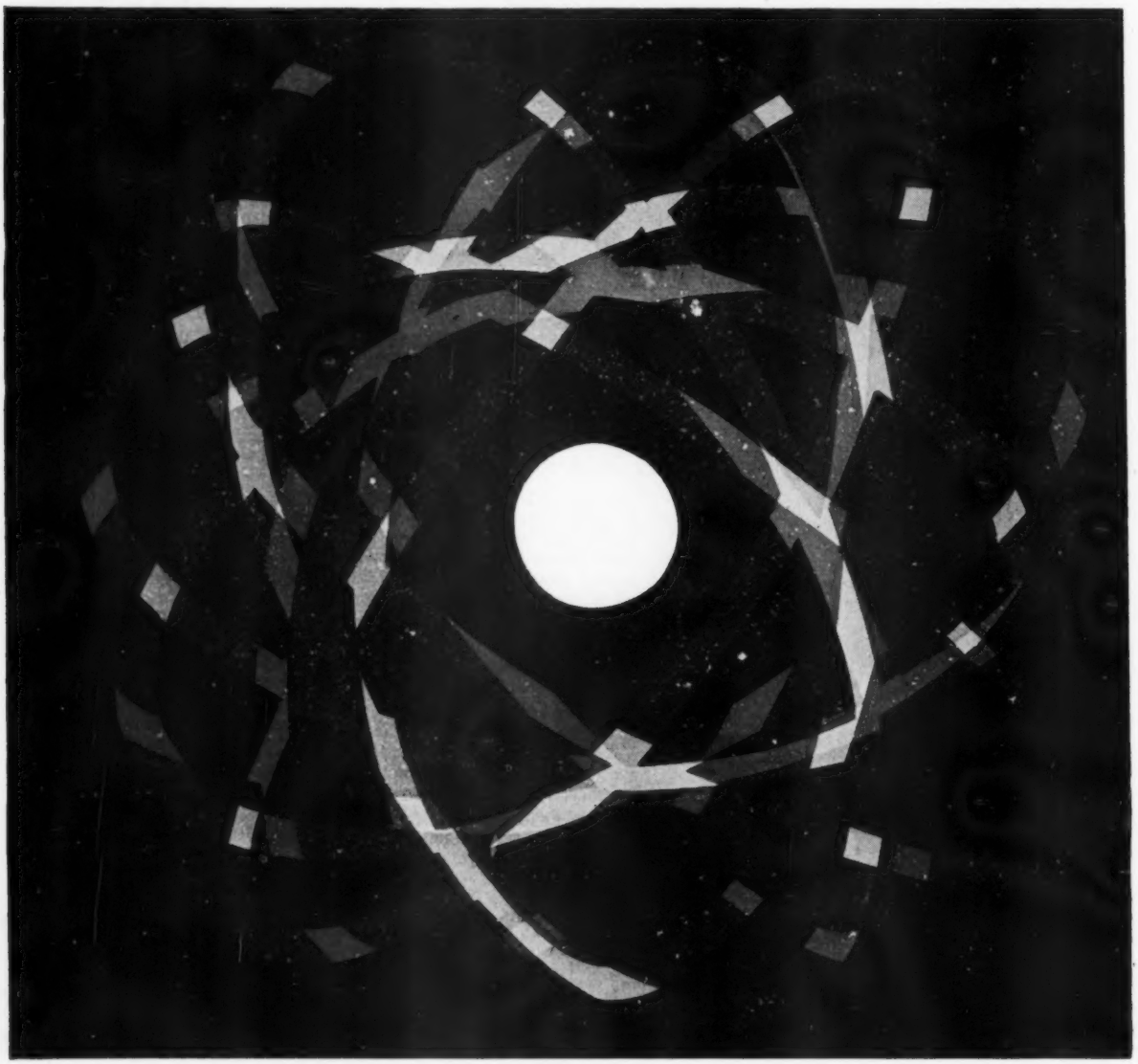

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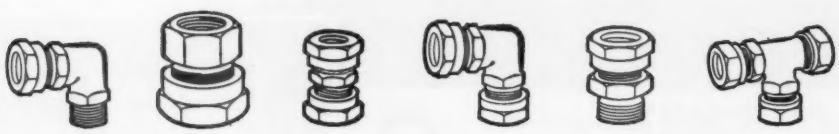

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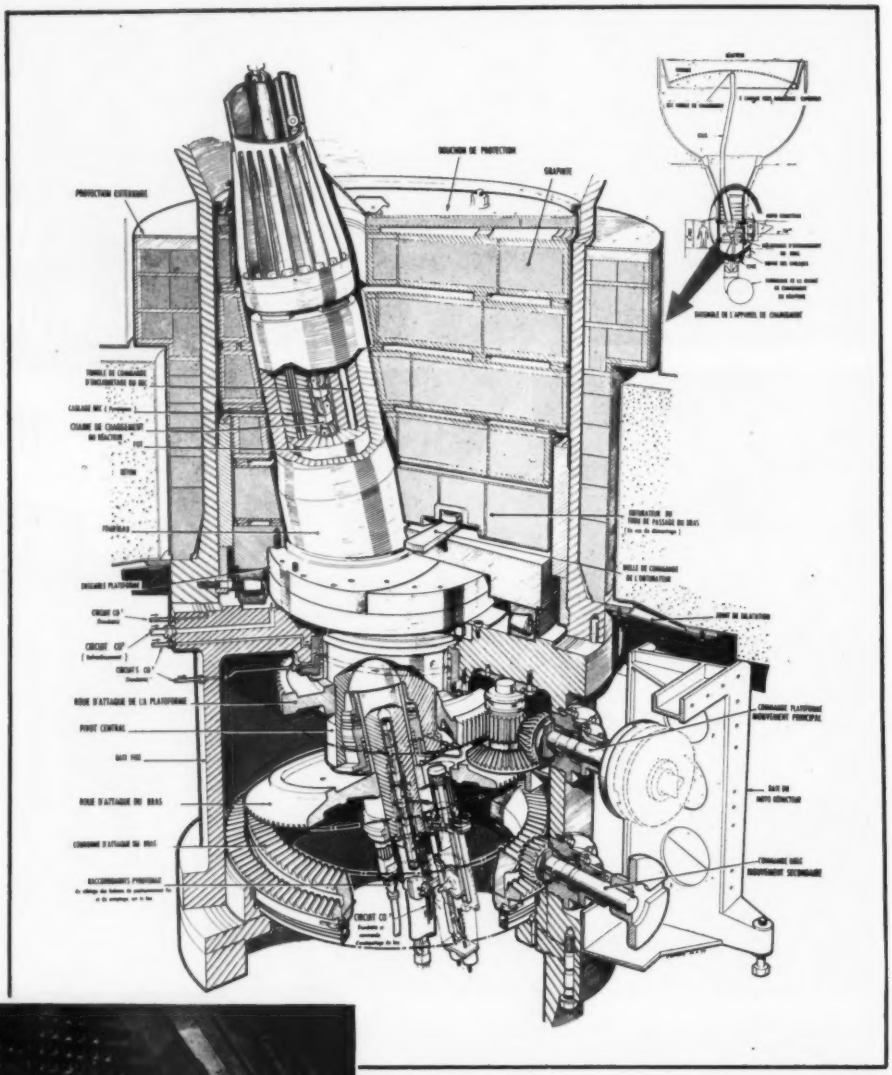
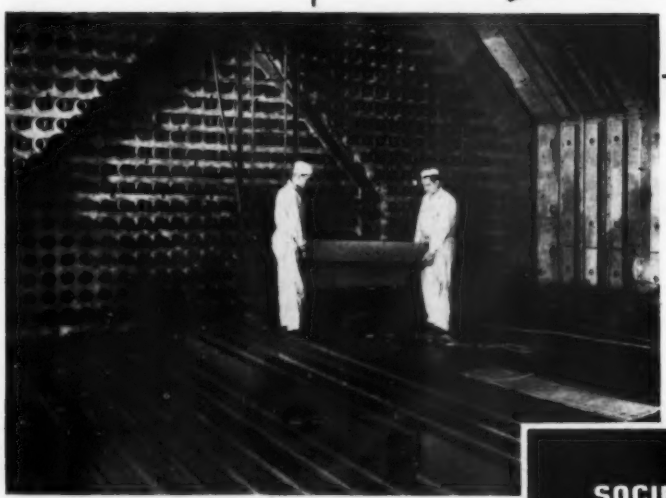
Loading and unloading device designed to operate through the lower section of the reactor developed by S. F. A. C. for EDF 1 Power Plant.





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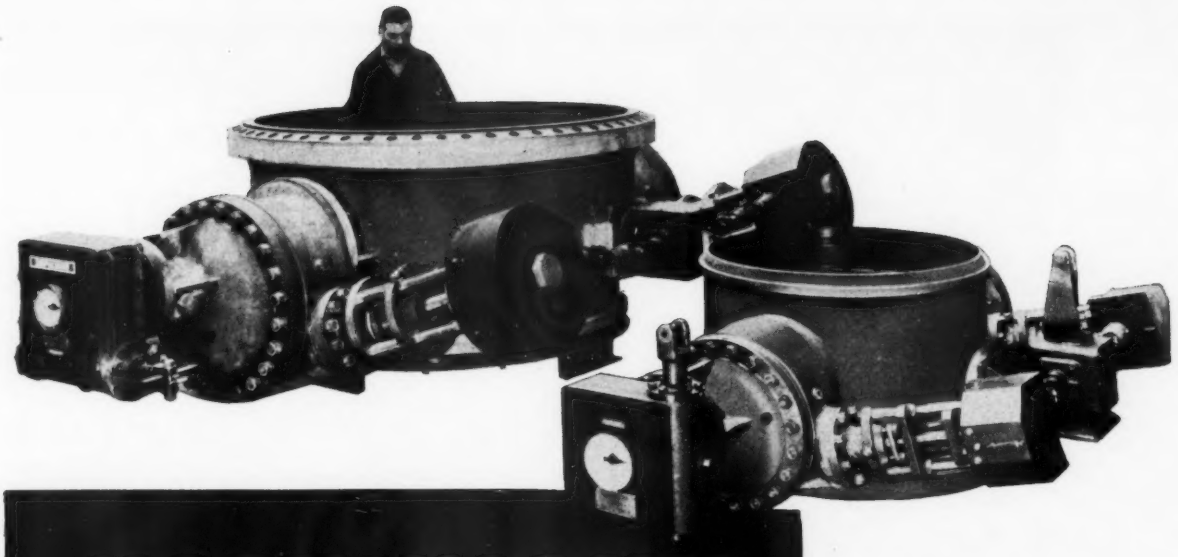
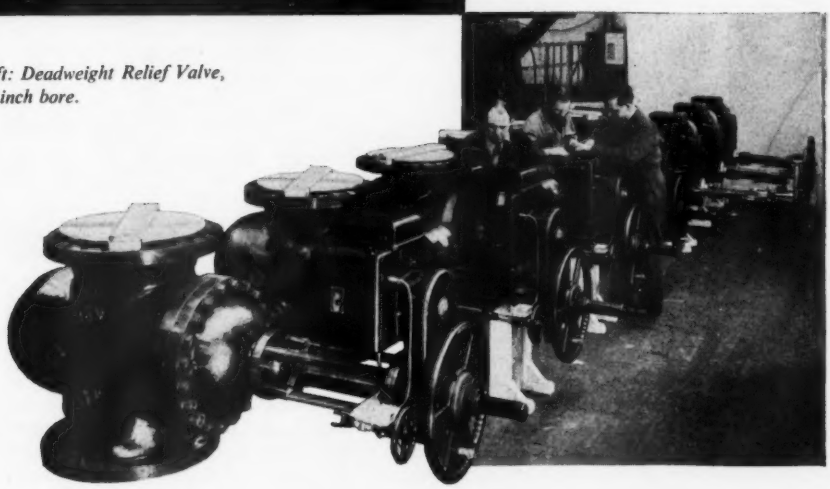


HOPKINSONS' VALVES FOR NUCLEAR POWER STATIONS

Above: "Tansphere" Valves for isolating CO_2 gas between reactor and steam generating plant. Supplied or on order for Bradwell, Hinkley Point, Latina and Trawsfynydd (Valves illustrated are 60 inch and 36 inch bore).

Below: Group of 24 inch electrically-controlled Hopkinson-Ferranti valves for a nuclear power station.

Left: Deadweight Relief Valve, 20 inch bore.



Specialised valves (some of which are illustrated) needed in nuclear power stations are naturally entrusted to Hopkinsons because of their vast experience in the manufacture of valves for exacting duties. But, additionally, Hopkinsons are supplying large numbers of their electrically controlled valves, desuperheating equipment, combined stop and isolating valves, automatic exhaust valves, steam traps and all types and sizes of stop valves.

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Dounreay	**Latina (Italy)**
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HV121

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the first portable, "desk-top" 400-channel pulse height analyzer

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decimal printer

Model 404
pulse height analyzer

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The Model 404 has a magnetic core memory that can be used in sub-groups of two or four; four separate inputs and associated amplifiers; internal pulse routing circuitry; pushbutton data transfer and display overlap; very low power requirements and many "system" advantages. And it can be used with the new solid state detectors.

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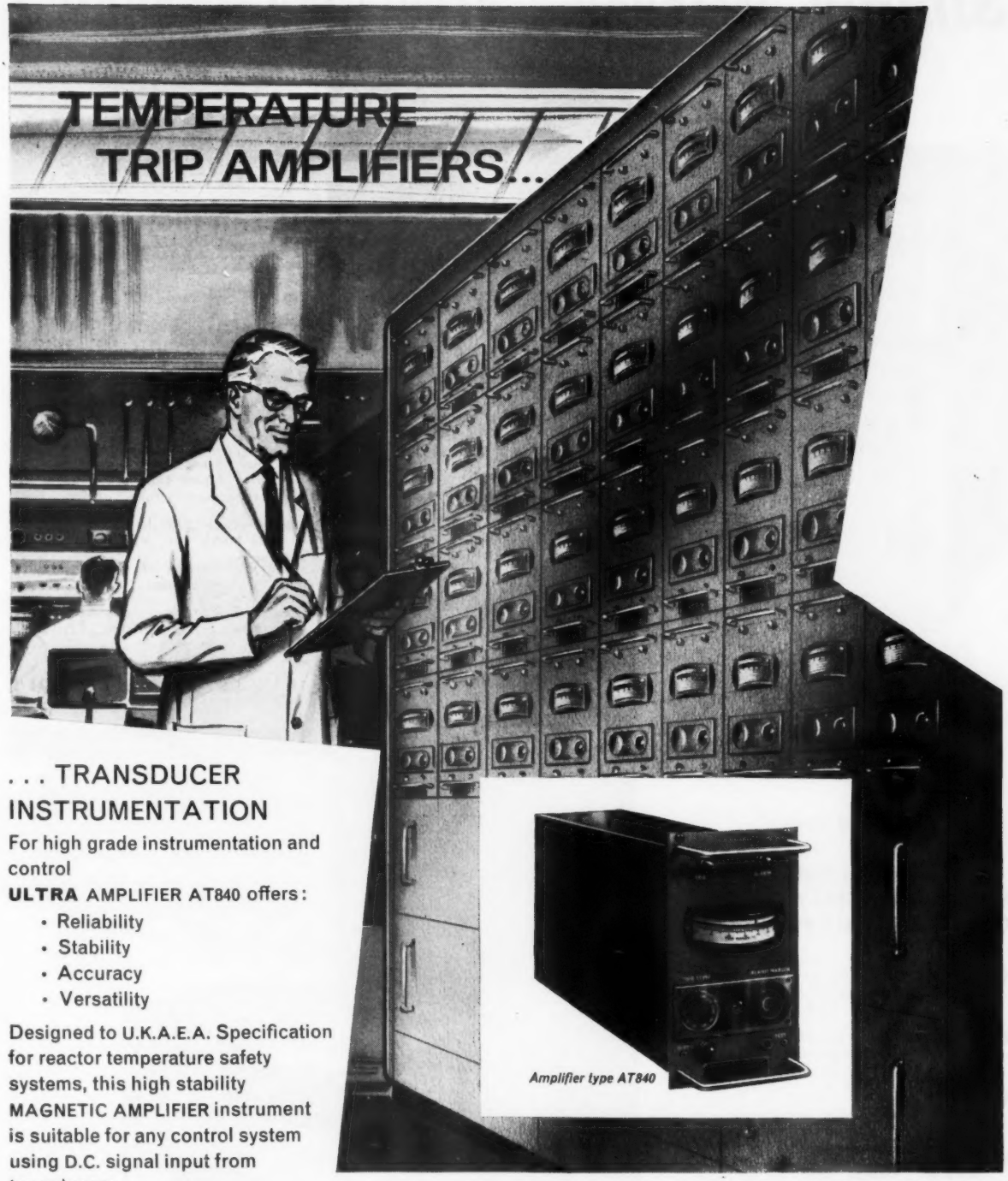

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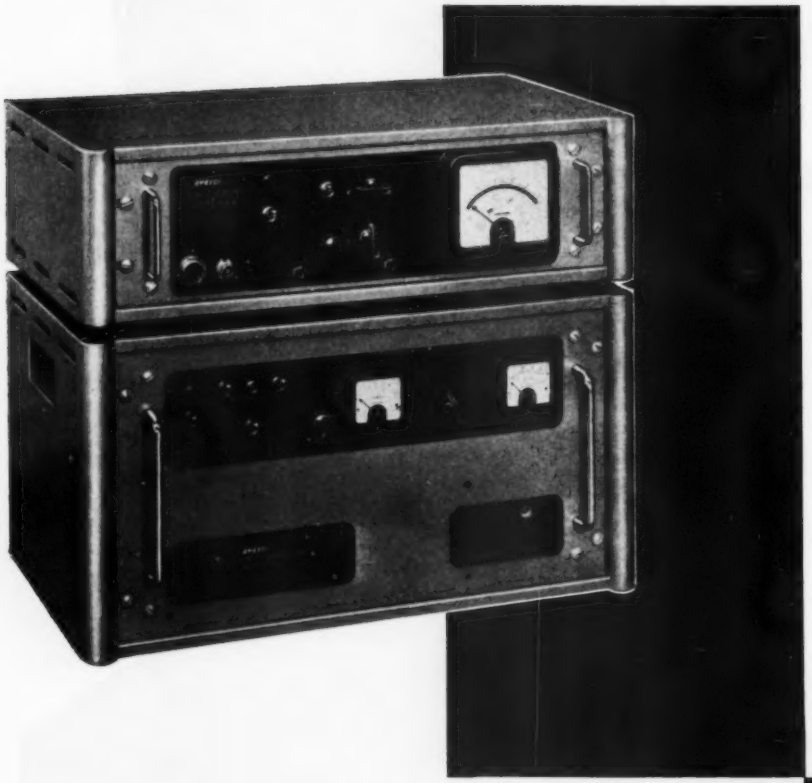

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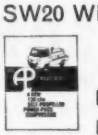

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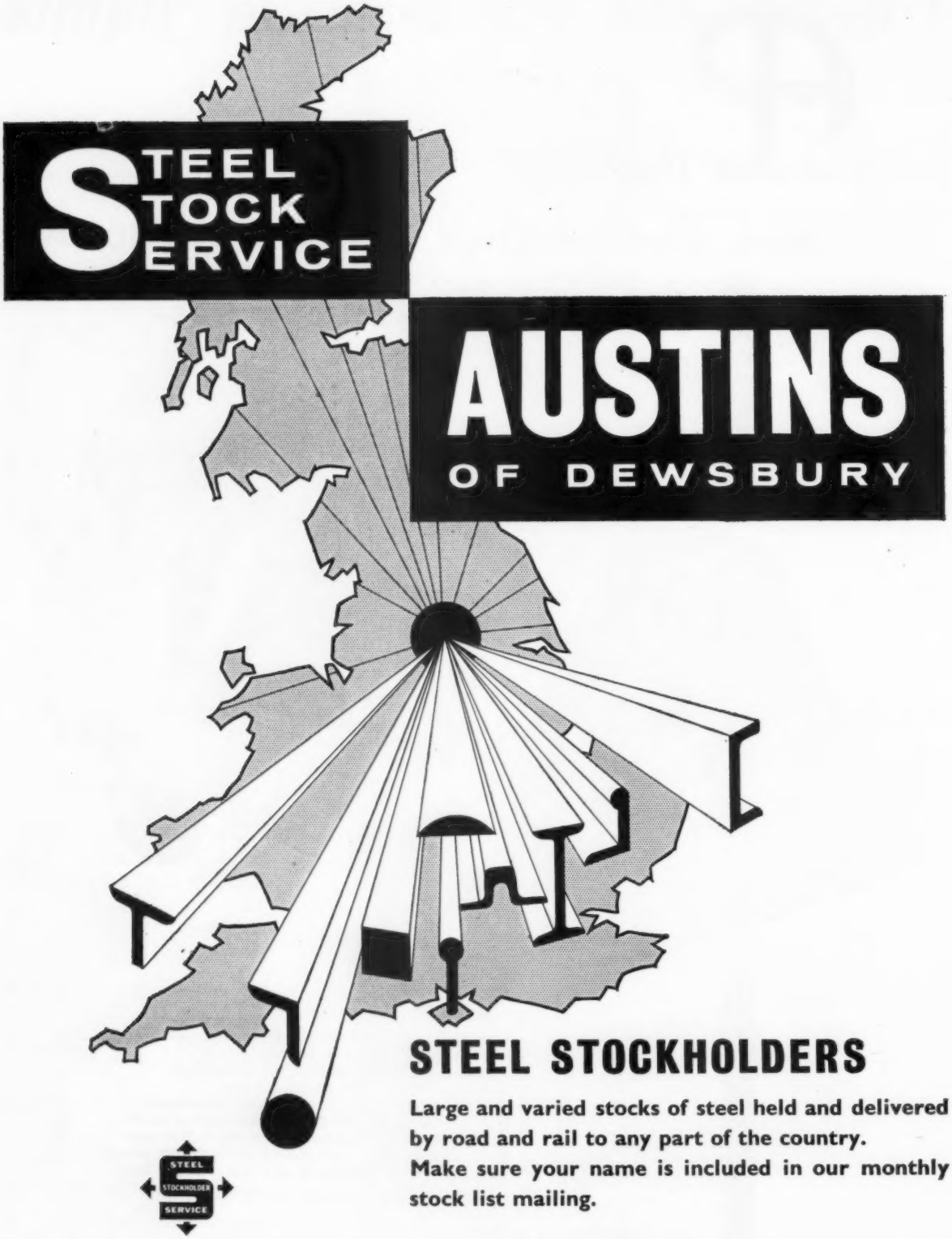

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GAS SEALING

The mechanical shaft seals which are mounted on the impeller shafts of the steam raising units, at the new Nuclear Generating Station being built at Hunterston by The General Electric Co. Ltd. for the South of Scotland Electricity Board are CRANE MK 65.

They will seal against the leakage of hot CO_2 gas (400°F.) as it leaves the steam raising units, and is circulated back to the reactor.

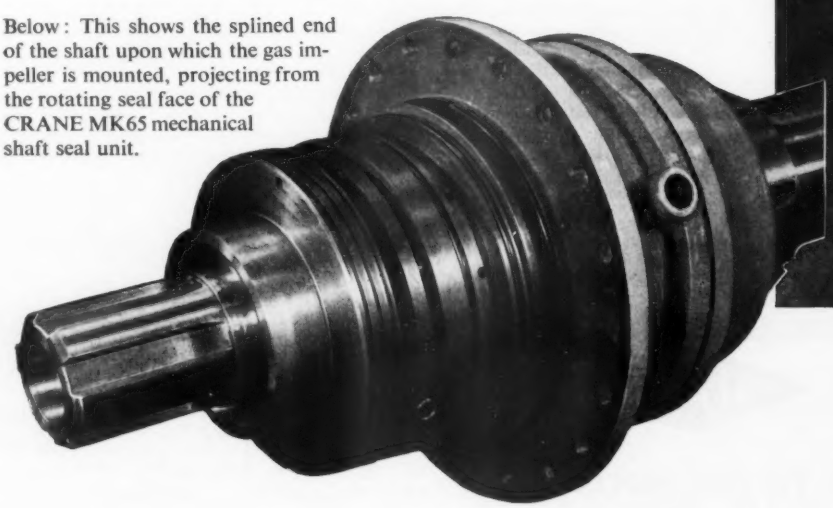
We are indebted to the Board and to The General Electric Co. Ltd. for permission to publish these photographs, which were taken by The General Electric Company in its Works at Erith, and on the site.

At the Engineering, Marine, Welding and Nuclear Energy Exhibition at Olympia we demonstrated how far we have advanced in the design of new seals for gas services—interested Engineers who did not visit the Exhibition should write for Information Bulletin No. 24 which was produced for distribution at the Exhibition.

Top Left: Two of the steam raising units are shown here already in position against the background of the general construction work in progress.

Right: The complete impeller shaft assembly is shown alongside the domed end impeller casing in which it will be installed.

Below: This shows the splined end of the shaft upon which the gas impeller is mounted, projecting from the rotating seal face of the CRANE MK65 mechanical shaft seal unit.



ISSUED BY THE MECHANICAL SEALS DIVISION OF

Crane Packing LTD OF SLOUGH ENGLAND

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This is the famous Tower Ballroom in Blackpool Tower . . . a luxurious setting which can accommodate 2,500 dancers and nearly 4,000 spectators. And above it soars more than 500 feet of steel—a graceful tower that dominates the town, a tower that is the symbol of seaside entertainment for the North of England. And at the heart of the entertainment, within the ballroom, is the famous organ—guarded by Walter Kidde fire protection equipment, as are important electrical sub-stations in the building . . . sure protection when so much is at stake.

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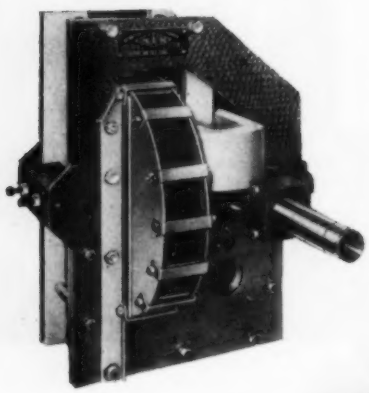
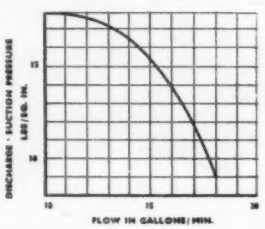


This electro-magnetic laboratory pump of the flat linear induction type has been especially designed for liquid metals. First produced in 1953, some of the early models have been operating continuously without overhaul . . . a tribute to our high grade workmanship. The pump is suitable for any metal or slurry having suitable characteristics and compatible with the 18-8-1 stainless steel pump duct, such as sodium, sodium potassium, mercury, lead, etc. Pumping rate is very flexible and is controlled by a VARIAC TYPE TRANSFORMER. Nominal bore is 1", liquid metals up to 400°C can be handled, or with fan cooling up to 600°C. Pump end fitting can be supplied to suit requirements, complete with flexible mounting and expansion couplings.

The performance curve below shows operations of pump with sodium potassium at 350°C, a circuit pressure of 30 p.s.i., and running at 210 volts.



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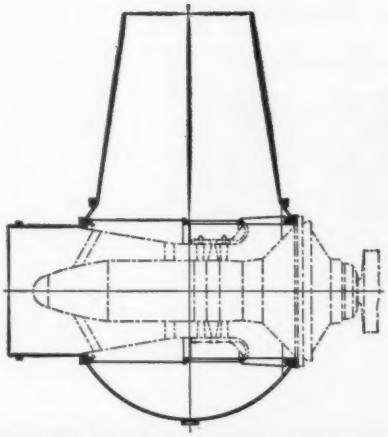
New thinking for Trawsfynydd

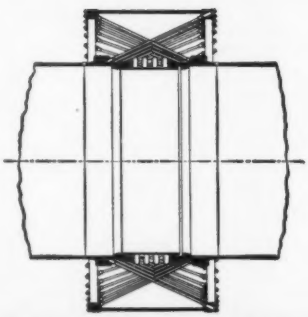


CO_2 CIRCULATORS

As every engineer knows, the thickness of plate required to contain a given pressure is halved if the vessel is spherical instead of cylindrical. It is odd—but nevertheless true—that it was not until our own engineers were confronted with the design of the CO_2 circulatory system for Trawsfynydd that the elementary principle was put into practice on large pressure pipework.
Besides halving the plate thickness spherical construction has other advantages. All welds are circular, can be prepared by machinery and are simple to X-ray.

CORNER BENDS

The same advantages follow when the same principle is applied to corner bends. In addition, the stiffeners required on cylindrical bends are eliminated. Internal tubes—not subject to pressure—provide a smooth gas flow.



EXPANSION JOINTS

It is standard practice to take up the expansion of large diameter pipework by flexing at what are essentially hinged joints. These of course have to provide restraint against axial forces—over 1,000,000 lb. in the Trawsfynydd ducting. The usual solutions, an internal metal tongue or a hinged joint are heavy, cumbersome and, moreover, flexible in one direction only. The hinge we have devised is flexible in *all* directions, by elastic straining of the high-tensile steel, restraining rods. The circumferential pressure is taken by a metal bellows, faired internally by a floating sleeve.

These ideas are not our only contribution to Trawsfynydd. As well as the complete CO_2 circulation system, we are building the whole of the generating plant, comprising steam turbo-alternators, condensing plant and feed heating systems.

R W G

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NON-OVERLOADING LINEAR PULSE AMPLIFIER NE 5202:

with 5 microsecond recovery for 100 times overload. Designed for scintillation spectrometry and pulse height analysis studies, this amplifier features high gain (50,000), high gain stability (better than 0·25% per week), good linearity, low noise (less than 40 microvolts at input), excellent overload characteristics, and operation at high duty cycles. Rise time 0·7 microseconds and integral linearity 0·15%. Preamplifier NE 5202A also available. Based on the double delay line differentiated Fairstein system, it consists of three high gain feedback groups, and a White cathode follower output.

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As NE 5302, but with output voltage range from 1000-5000V.

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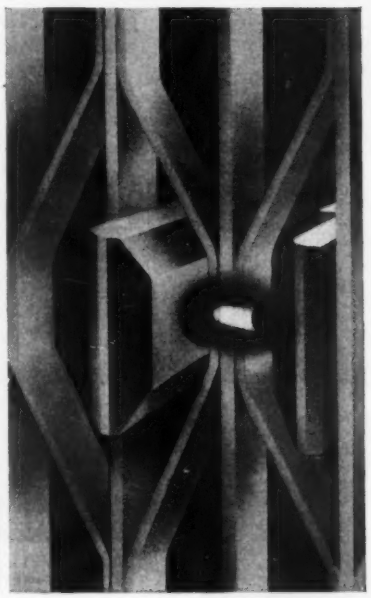
the unique SAFETREAD resistance welding method cuts corrosion



"Safetread" steel flooring is *homogeneously resistance welded under pressure* — thus closing the grain of the material and providing a highly corrosion-resistant joint of great strength. "Safetread" floors installed for many years under rigorous conditions show that the least corrosion has taken place at the point of welding. Welded through the neutral axis of the main bar, maximum strength and lateral stability is also gained.

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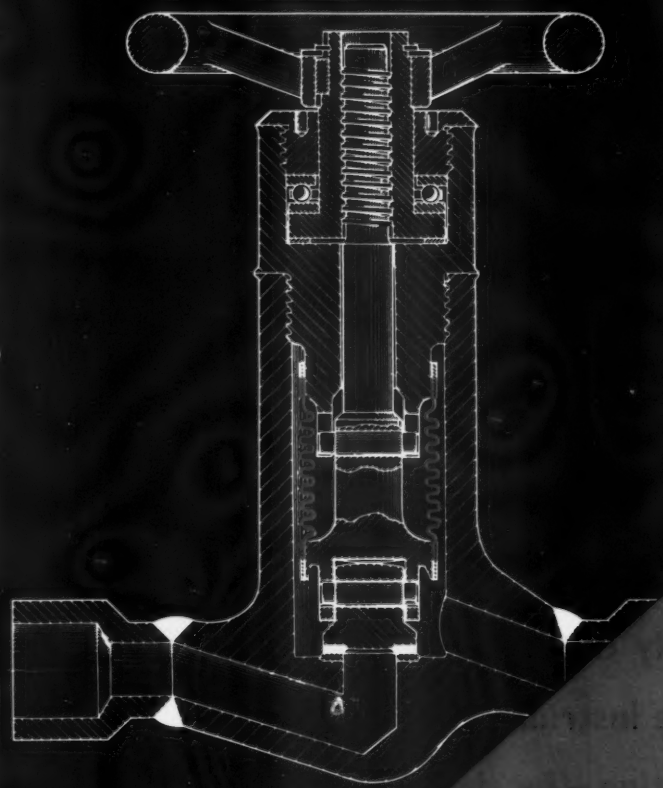
for NUCLEAR INSTALLATIONS



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Photograph by courtesy of International Combustion Limited, Derby, who have installed in their new Heavy Shop a FIELDING 3,000 tons Direct-Acting Vertical Plate Bender; a FIELDING 3,000 tons Vertical Hydraulic Plate Bender and a FIELDING 4-column Flanging Press of 2,000 tons power

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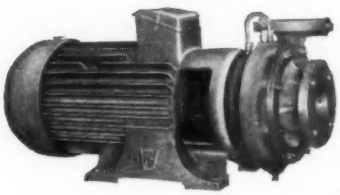

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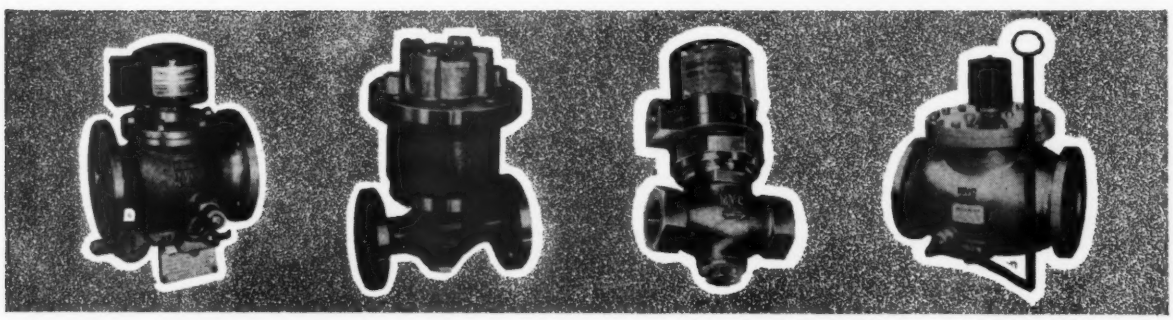

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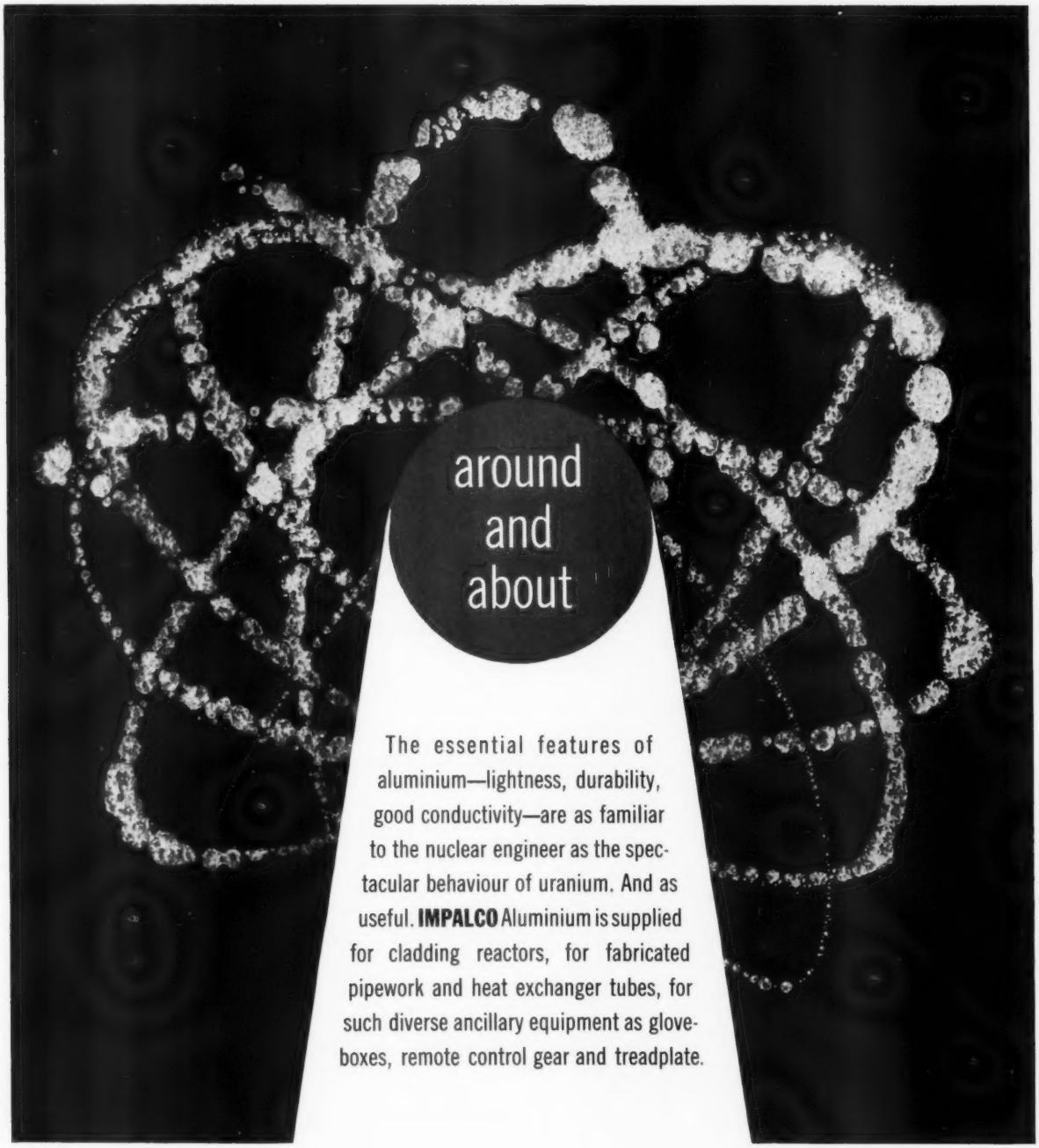

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(*a*) They had to provide a high degree of flexibility.
(*b*) A uniform tensile strength of approx. 75 tons throughout their length was required.
(*c*) They had to have a surface completely free from machining marks.

These bars, after extensive experiments and tests, have been produced and incorporated in the mechanism. In use, they show "extremely high fatigue strength in the high deflection range".

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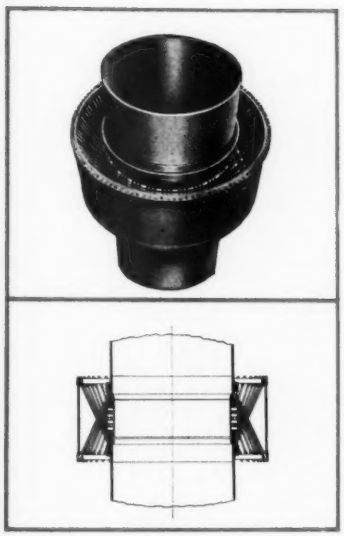

Bellows Restraint Mechanism, designed by Richardsons, Westgarth & Co Ltd, for the Trawsfynydd Nuclear Power Station.

A.P.NEWALL

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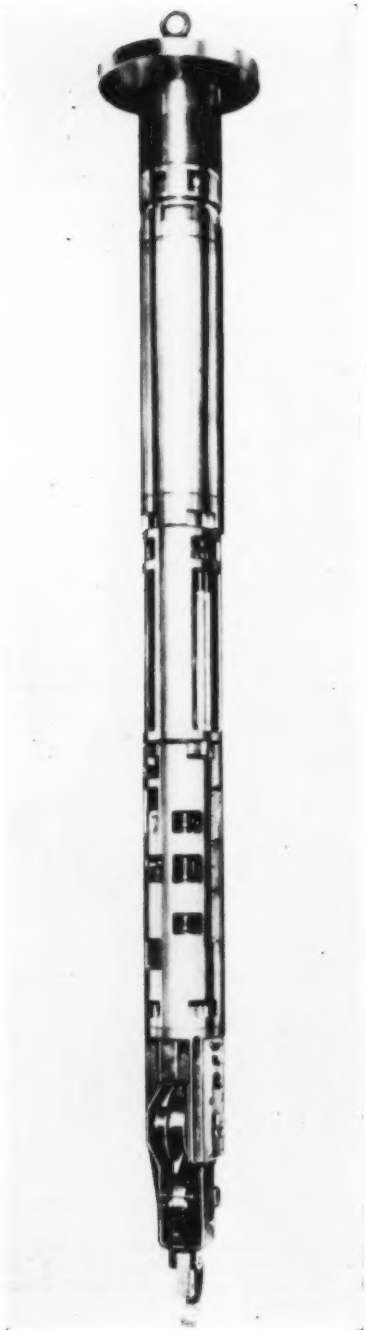

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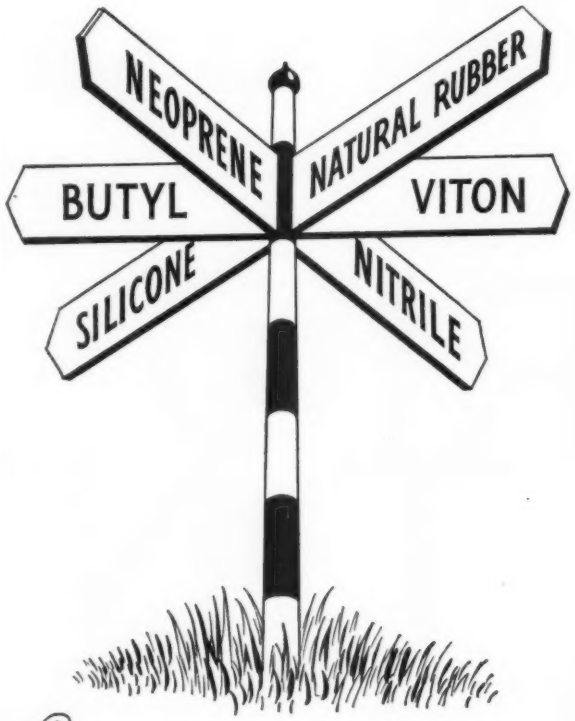

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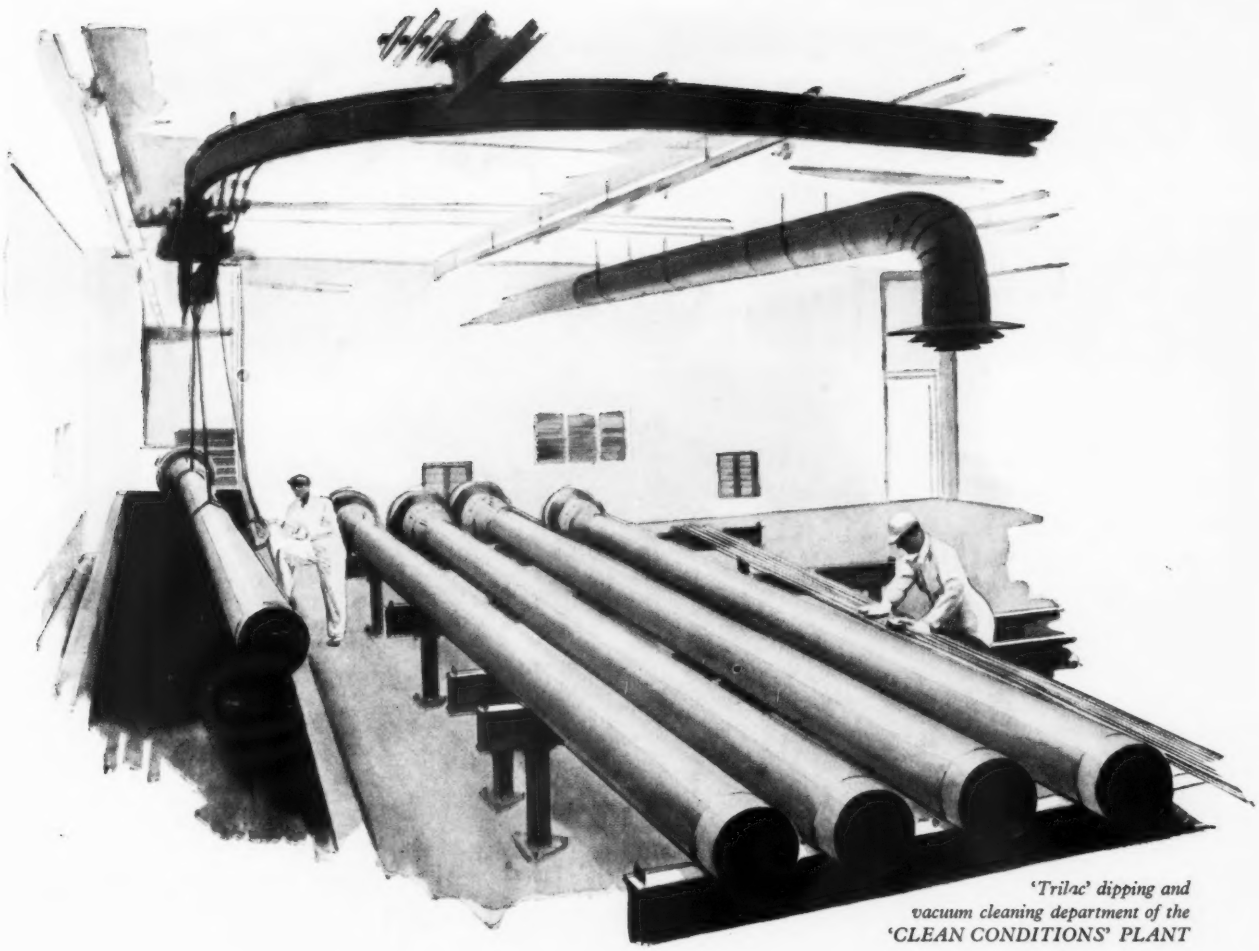

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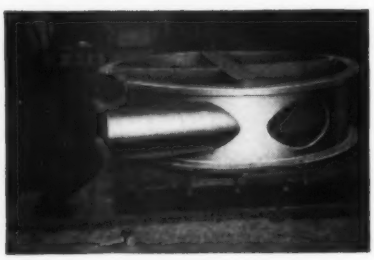

The Aluminium Bronze water and return box equipment illustrated, was fabricated and welded by Butterfields in co-operation with N. C. Ashton Ltd., who supplied the plate, forgings and welding wire. Welding throughout was by inert gas processes, and mainly by inert-gas metal-arc. Demonstrating how effectively these anti-corrosion Alloys can now be welded to other materials, the mild steel flanges in this equipment were layered with Aluminium Bronze.

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JULY 1961 VOLUME 6 NUMBER 63

VIEWPOINTS *letters to the Editor*

Kahl Control Rods

SIR: Your January issue (*Worldview*) page 60, refers to the Dresden control rod failures. Your readers may be interested to read how we avoided this problem in the Kahl plant. First of all it should be noted that so far no troubles similar to the Dresden control rod failure have been observed in the Kahl plant at all. However, in the light of the experience obtained at Dresden with the performance of the steel type Armco 17/4 PH, it was decided as a purely prophylactic step some time ago to set up a replacement programme for those parts of the control rod drives of the Kahl plant which, like Dresden, have been fabricated out of this type of steel, as subjected to a heat treatment at 900°F.

According to this programme it was resolved to replace such parts either by another or by the same steel type, yet in the latter case subjected to a heat treatment at 1100°F. The replacement programme will be concluded shortly during the next month so that the reactor can then be made critical again and brought up to power, provided the licence for full power operation will have been issued by our authorities by then.

DR H. J. BRÜCHNER

AEG, Frankfurt (Main)

Nuclear Ship Delay

SIR: I whole-heartedly agree with your May leading article headed 'Nuclear Ship Indecision.' Unless the Government's deadening procrastination is ended sharply and a definite building programme started now, other firms will have to follow the sad example of Hawker-Siddeley and disband their marine reactor design teams; over a million pounds, three years' work wasted.

Three years ago Mr MacMillan repeated the Civil Lord's promise of a nuclear propelled ship ready for sea trials by 1964 if all went well. Even buying a reactor off the shelf from the US, as was done for the submarine, will not enable him to keep it. Why did he transfer responsibility for merchant shipbuilding and repair to the Ministry of Transport last year, without consulting the Admiralty, indeed without even informing them? Perhaps Guy Wilson as Rear Admiral Nuclear Propulsion was too forceful and too knowledgeable for some people's liking. But for Mr Ingamells' public-spirited action in continuing to direct merchant shipbuilding and repair under the new management, marine nuclear work would have stopped then. As it was, the Numarcom Committee went on despite the politicians. Let us hope that the appointment of Vice-Admiral Hughes-Hallett as Parliamentary Secretary for Shipping in the Ministry of Transport will give Mr Ingamells the informed backing which the Admiralty used to provide.

Those who oppose the Cunard loan and subsidy (only £3¼M grant) seem to forget that our ships have to compete with very heavily subsidized foreigners and with aircraft, whose development expenses are borne almost entirely by the State and whose operation is heavily subsidized, directly and by paying for the upkeep of airports. Sitting back with a sigh of relief, having demonstrated that on paper nuclear power is not at the moment economically competitive at sea, is by no means confined to Conservative backbenchers; it is the general excuse for doing nothing by many whom one would expect to have more foresight.

I do not advocate accepting one of the present tenders for a reactor with little development potential, to get a nuclear ship to sea at once, but I do maintain that we must *now* draw up a development and building programme for a marine reactor with economic prospects. The HTGC Reactor is too uncertain and too far off, and a General Dynamics' version using a closed-cycle gas turbine is not suitable for merchant ships. We can safely leave them to prove that by experience.

If a Cunard liner with four steam-cooled heavy water reactors were to be designed now, making proper use of the space and weight saved by not having to stow 8000 tons or more of fuel oil and by the absence of funnels uptakes and air downtakes, to fine the lines of the ship and reduce the weight of her hull, she would be a cheaper ship to run than her sister whose order is now to be placed. But the prototype reactor must be started at once and the work on this and on designing it into a ship go full speed ahead. Incidentally the absence of funnel gases and smuts will result in a much cleaner and smarter ship and passengers will much appreciate this. Having spent so much of my life trying to burn oil without smoke or smuts, I do assure you that it is no easy matter.

Your last suggestion, tamely to join in the European project, I deplore as a confession of defeat. Two per cent of our annual expenditure on the AEA wisely allocated, could within six years, give us a wholly British marine reactor at sea and put us back in the van of progress. Fitted in a liner it will win back the Atlantic Blue Riband and much of our vanishing maritime prestige. Can we not afford this? Or rather, can we afford *not* to do this, and accept the loss of the last vestige of our vaunted shipbuilding supremacy.

CAPTAIN H. F. ATKINS

Vickers Nuclear Engineering Ltd., London, S.W.1

Reactor Control Symposium

SIR: I would like to correct a misstatement in Dr Taylor's account of this Symposium, which appeared in the May issue. The name of my Company is given as Research Enterprises Ltd. and not Nuclear Enterprises Ltd. as it should be.

D. H. PRINGLE, CHIEF PHYSICIST

Edinburgh, 11

The Hayward Tyler glandless circulating pumps for the C.E.G.B's Nuclear Power Station at Trawsfynydd in Merionethshire, North Wales, are of inverted construction with the water-filled motors underneath the pump impellers. Under certain conditions this arrangement offers important advantages.

Trawsfynydd Power Station has a scheduled output of 500 MW. The high and low pressure circulating systems operate at 1000 and 325 P.S.I.G. and a total of forty-eight Hayward Tyler glandless circulating pumps are being supplied through International Combustion Ltd.

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OPINION

What are the plans for plutonium?

THE IMMINENT START-UP of the first CEGB nuclear power stations at Berkeley and Bradwell, to be followed in stages up to 1966 by six further stations, again focusses interest on the problem of what is to be done with the cumulative build-up of the plutonium by-product. Mr. J. L. Gillams of the UKAEA, London, has recently put the annual plutonium output per 1000 electrical megawatt-years as varying from 600kg, for the earlier magnox stations, to 450kg, in the later types; by 1965 the reserve will be around 1000kg, increasing to over 9000kg by 1970 and to over 20,000kg by 1975.

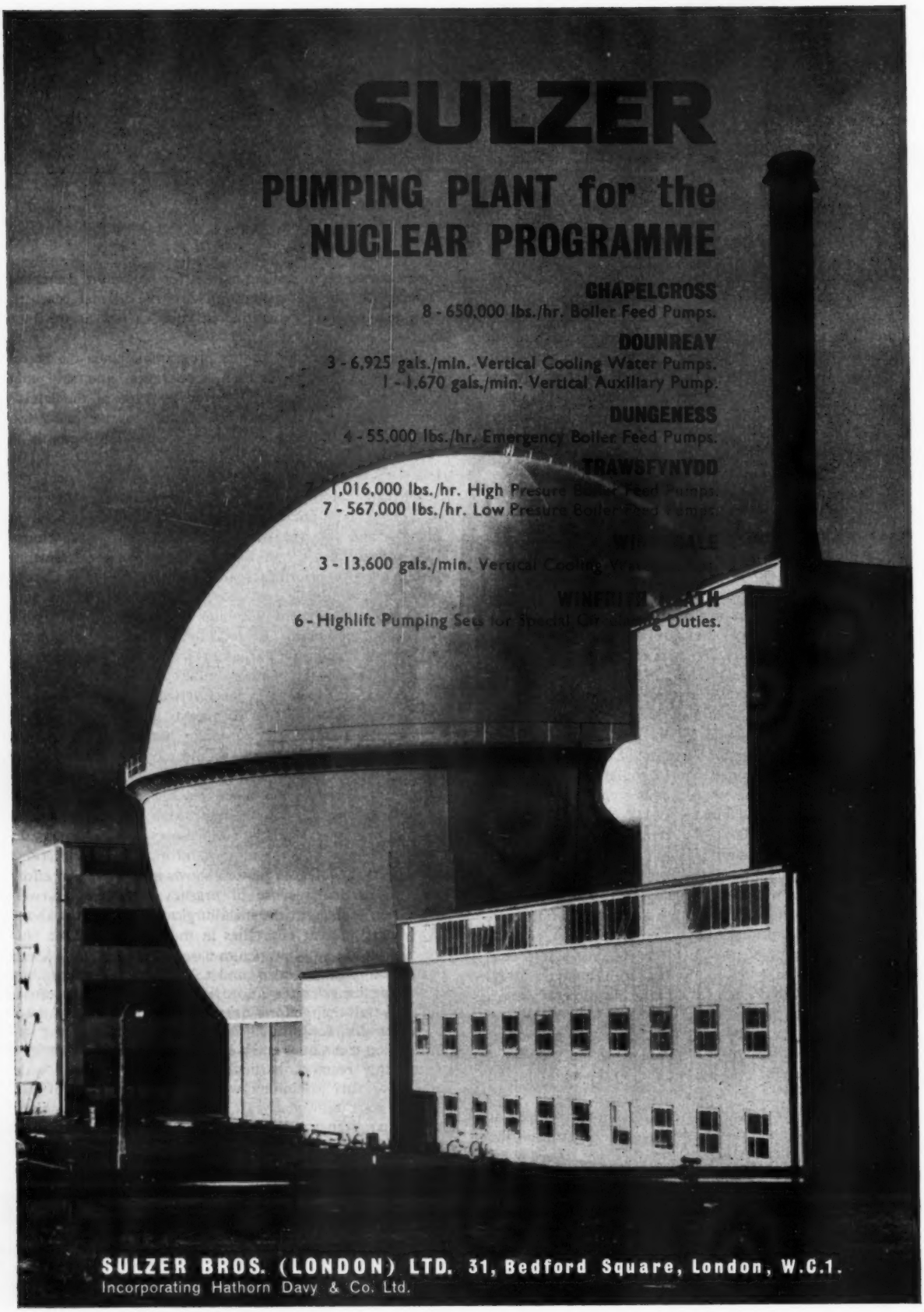
On the basis of the current UK buy-back price of £5000/kg, in fifteen years hence the value of this stock-holding will be in the region of £100 million—quite an asset if a use for plutonium is established. How fast this stock-piling is to proceed after 1970 will depend on a number of factors: the proportion of the CEGB's 3000-4000MWe annual building programme to be allocated to nuclear power, the outcome of the AGR and HTGCR projects, load factors and burn-ups. What is certain is that without this buy-back price nuclear generating costs would be 10% higher. The fact that credit of this size is being made reflects some faith in the future of plutonium burning reactors. That confidence in the fast reactor is not complete, however, was reflected in Sir Christopher Hinton's evidence to the 1959 Select Committee on Estimates on the possibility of future increases in plutonium credit. His reply indicated a lack of conviction.

Nevertheless, a use has to be found for plutonium, one that is economically sound. At one time the enrichment of natural or depleted uranium for use in thermal reactors was mooted as a promising development. The Plutonium Recycle Test Reactor in the USA which will soon be operating at 70MWt is primarily designed for this purpose; its first core loading of 85 fuel elements includes about one-third enriched with 1·8% plutonium in aluminium alloy. So far as the UK is concerned work in this direction seems to have stopped, through work concerned with the AGR and HTGC continues. The near future must lie in the development of fast reactors, developing up to 1000MWt, which will use about one ton of plutonium to about 10 tons of uranium.

According to Sir John Cockcroft in a recent paper at Trombay the plutonium that will become available in the 1970's will be sufficient to construct at least 1000MW of breeder power stations each year, with breeding increasing uranium utilization a hundred-fold over earlier stations. The pattern of nuclear power then suggested for the 1970's is a combination of plutonium producing thermal reactors such as the first Magnox stations, the AGR and the plutonium burning fast reactors. This is the integrated programme that was put forward a few years ago whereby the existence of an assured market for plutonium decreased significantly the net generating cost of thermal reactors, with fast reactors generating at costs as low as 0·3-0·4./unit at a high load factor.

What has happened to the programme since the Select Committee recommended an acceleration and said that major problems should be solved by 1966 at the latest? The DER has had its share of troubles as we know too well but so has the Enrico Fermi project. On the basis of comparison with progress in the USA and USSR the UK seems to be holding its own, but our technological developments could have been more advanced than they are; it is ten years since fast reactor studies commenced at Harwell and nine years from the conception of the Dounreay design. In 1959, it was well down on the Industrial Group's list of priorities; associated work both at Capenhurst and Windscale had ceased, and there was the suggestion that insufficient plutonium was being made available for civil experiments. As recently as February this year, Mr Denzil Freeth, the Parliamentary Secretary for Science, told the House of Commons that the Authority did not plan any major change in the level of work at Dounreay. If the stretch-out of the civil nuclear power programme is making the solution of plutonium burning problems less urgent, then the Authority should say so—reluctance to release full details on research and development achievements only leads to the belief that all is not as well as it could be. At least, that is the impression that may be gained when reading Dr Waldron's otherwise excellent review in this issue, and from the lack of information elsewhere.

The present research pattern shows a scattering of effort with no particular sense of urgency anywhere. Harwell have been looking at the metallurgical problems for about five years; present effort lies in the development of plutonium alloys and plutonium-based ceramic fuels. Some irradiation work is also under way. Aldermaston has developed considerable know-how on physical properties, but how far their efforts are aiding civil developments is a matter for conjecture. Dounreay is concentrating on fabrication techniques and work is to be done on Winfrith's zero-energy reactors, particularly on Zebra where a wide variety of fuel assemblies will be investigated. But this will not start until next year. As for industry no plutonium as yet has been handled and any development work that is being done on ceramic fuels is via the analogous use of uranium. It is to be hoped then that these various efforts will be more closely and carefully integrated. What is now needed to dissipate gloom about the fast reactor's future is a precise statement of official policy regarding the integrated programme, a candid review of plutonium progress and the targets to be attained, followed by a realistic assessment of whether or not more effort, scientists and equipment are needed,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WORLDVIEW

the month in atomic energy

EUROPE

Two out of three will offer concrete for Oldbury

London Engineers of the three consortia are hard at work preparing final details for the CEGB Oldbury nuclear power station tender due in on August 14. Interest centres around whether a concrete pressure vessel will be chosen and particularly whether the boilers will be enclosed in the prestressed concrete structure. *Nuclear Power* understands that UPC (GEC and APC) will offer two designs with considerable economies claimed for the concrete alternative. The Nuclear Power Group are expected to submit a concrete design while the English Electric, Babcock and Wilcox, Taylor Woodrow group are expected to refine the Sizewell design.

Opinions as to the savings ensuing from using a prestressed concrete vessel vary widely amongst designers. The amount of steel used for the cabling and the gas-tight liner may be as much as for a 'conventional' steel vessel. Although there will be some saving here because of the lower quality steel needed. What economies there are will be due to a entirely different approach to construction and it will probably remain for actual construction experience to prove that these are substantial.

UK CEGB opens its Berkeley laboratory

Berkeley UK The Central Electricity Generating Board's own nuclear laboratories, built here at a cost of £2 million, have now been officially opened. The CEGB's nuclear research is at present scattered through several establishments, but most of it will be gradually concentrated here under the leadership of Dr Haigh. The first task is a drive to clear up the remaining problems on the 'first-round' gas-cooled stations — one of which is right next door.

An International Conference on the Properties of Reactor Materials and the Effects of Radiation Damage provided a good send-off for the laboratory. On the first day of the Conference, Lord Fleck performed the opening ceremony, an activated device being appropriately used to trigger the electro-mechanical operation of the main doors.

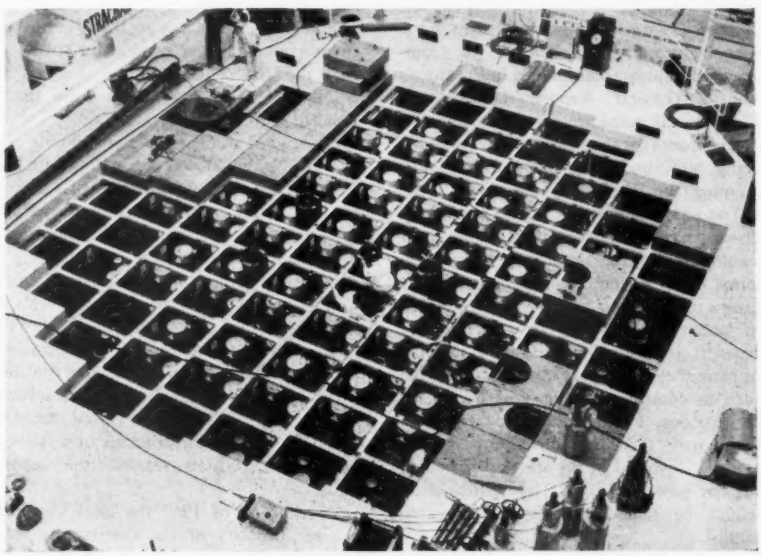
Technical sessions were held in the Great Hall of the nearby Berkeley Castle, which has surely not before heard such erudition. And the discussions were erudite but with the sense of purpose for which these new laboratories have been established; that is to study the operational problems of the new nuclear reactors with the best available intellectual and practical techniques. The laboratories will have a high ratio of scientific staff to assistants and, while the prime aim is operational research, fundamental work will also be encouraged to maintain a high level of critical and creative activity. sessions on damage flux, neutron spectra, lattice defects, mechanical properties, fracture, corrosion and dimensional stability. More than 120 members attended from sixteen countries including a delegation from the USSR led by Dr Konobeevsky. Full reports on the conference and the laboratories will appear in next month's *Nuclear Power*.

• **United Kingdom** Excavation work for the two reactors and turbine house at the Dungeness nuclear power station has been completed. Construction is now centred on the pouring of support walls in No. 1 reactor and on the erection of the goliath crane support tower.

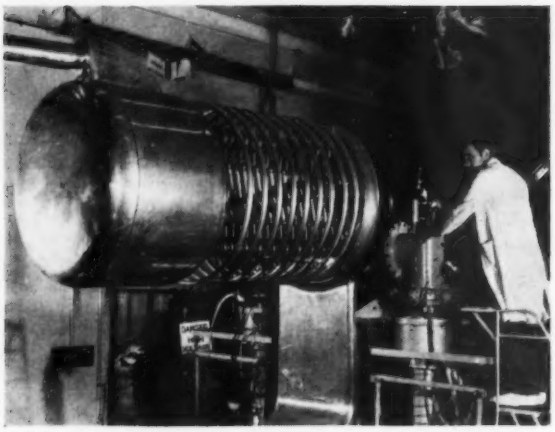
• **Switzerland** The nuclear power station planned for Lucens is expected to be completed by 1964 at a total cost of 70 million francs.

• **Eurochemic** The director general and the technical director of Eurochemic recently visited Rome for a meeting with CNEN Secretary General, Prof. Felice Ippolito, to discuss finances of the company and increased Italian staff participation.

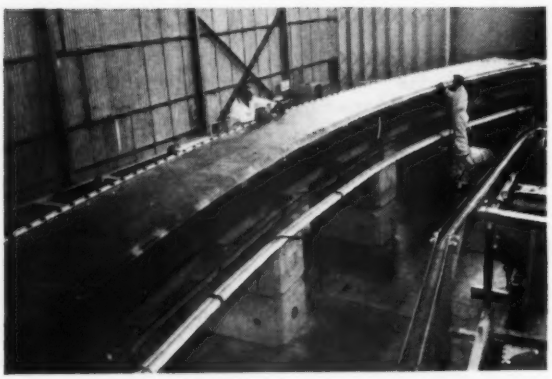
• **United Kingdom** Nearly 900 delegates, with an equal number of guests and visitors, attended the 13th British Electrical Power Convention at Eastbourne, held from June 12th to 15th. An interesting innovation this year was the overseas contribution from Dr A. E. Grauer, chairman and president of the British Columbia Electric Co. Ltd., surveying Canada's electrical power industry.



BRADWELL NEARLY READY Work on the pile cap of the No. 1 reactor at the Bradwell 300 MW station is in the final stages. This Nuclear Power Group station is shortly to go critical and is expected to be commissioned by the Central Electricity Generating Board in 1962



NIMROD PREPARATIONS This formidable 600 keV ion gun will supply pulses of protons to the 15 MeV linear accelerator injector for NIMROD, the 7 GeV proton synchrotron being built at the Rutherford High Energy Laboratory. NIMROD, which consists of a ring-shaped magnet 150 ft in diameter, weighing 7000 tons, is due for completion in 1962



A 50 ft section of the NIMROD glass reinforced epoxy resin double-walled vacuum vessel through which protons are accelerated is shown under test. This is the first occasion on which laminated plastics have been used for the construction of a vacuum chamber for a proton synchrotron

IAEA, Yugoslavia plan small reactor

Vienna The building of a small/medium-sized demonstration nuclear power plant in Yugoslavia has been the subject of talks between the International Atomic Energy Agency and the Yugoslav Atomic Energy Commission.

At the recent IAEA Nuclear Electronics Conference, Mr Sterling Cole, Director-General, first gave the news that these talks had taken place. He added: 'The design, construction and operation of such a plant would be of special interest to the less developed countries, especially in training technicians and obtaining cost data.'

Mr Cole stated that it had been agreed that both the Federal Nuclear Energy Commission of Yugoslavia and the IAEA Secretariat should initiate studies of the technical, legal and financial aspects of such a joint undertaking. The Yugoslav Commission is to prepare more specific information on this proposal and the contribution which it might make to the joint undertaking.

The Director-General said he looked forward to further close and fruitful discussion with the responsible Yugoslav Commission authorities.

Euratom report describes fuel subsidy plan

Brussels Details of proposals to assist in the manufacture of fuel elements for Community countries are contained in Euratom's Fourth General Report. Under this, Euratom will subsidize the manufacture of fuel elements for the nuclear power stations being built under the US-Euratom programme (See *Worldview*, June p 53).

The report states that as the number of power stations under construction is still insufficient for the Community's needs in terms of experience, the Commission has drawn up a plan to encourage the building of power reactors of various promising types. It proposes to participate in the cost of manufacture of fuel elements, to provide fuel, to contribute to the cost of reactor construction or to underwrite the extra costs, over those of conventional power stations, involved in the start-up period of nuclear power stations. This participation would be financed under the research budget.

Among the factors to be taken into account when aid was asked for would be the size of the proposed plant, its likely contribution to the industrial potential of the Community and the information it would provide relevant to the lowering of investment or power production costs. So far, the report adds, three companies, SENN, SIMEA and SENA have made detailed requests for Euratom aid.

On reactor studies, the report points out that the Commission is negotiating with the French CEA for the joint study of a power reactor based on the high-performance, gas-cooled reactor concept. Euratom has also taken the first steps in implementing a programme for research on fast reactors and a contract has been signed with a Belgian study group in the field of neutron physics and further co-operation is planned with French and Belgian centres. Work is still continuing under the contract signed in 1959 with the Dutch KEMA company for the construction of a homogeneous suspension reactor, the report adds.

At the end of 1960 the total installed nuclear capacity of the Community was only 80 MW, from the three Marcoule reactors in France and the Kahl/Main reactor in the Federal Republic. During the current year a further 80 MW is to be provided from the BR 3 reactor at Mol (Belgium) and the first Electricité de France plant EDF 1 (70 MW) at Chinon. In the following years further power reactors are also expected to come into operation: 1962: 170-200 MW EDF 2 (France); 200 MW SIMEA plant at Latina (Italy). 1963: 150-230 MW SENN plant (Italy); 15 MW Julich reactor (Germany); and 1965: 300-500 MW EDF 3 (France); 100 MW EL 4 (Monts d'Arrée, France).

Altogether, by the end of 1965, power stations under construction or planned will provide up to 1565 MW of capacity. To this may also be added the BEWAG (Berlin) and KBWP (Baden-Württemburg) projects each of 150 MW, the Italian SELNI Company's 160 MW project, and one in Holland. All of these are under study or discussion.

UK-USSR sign five year agreement

London Greater co-operation between the UK and the Soviet Union is expected to follow the signing of a five year agreement for collaboration in the peaceful uses of atomic energy between the two countries. The first visits of teams of scientists under this agreement will take place later this year.

The agreement was signed on May 19 by Professor V. S. Emelyanov, chairman of the USSR State Committee of the Council of Ministers for the Utilisation of Atomic Energy and Sir Roger Makins, chairman of the UKAEA. It followed two days of talks during a week's visit by a team of Soviet officials.

Provided for under the agreement is an exchange of information and visits on nuclear physics, solid state physics, basic radiation chemistry, inorganic chemistry of elements of importance in nuclear science and technology, research on isotopes and research on the application of isotopes, plasma physics, high energy physics, reactor physics and experimental fast reactors. Conferences and visits for discussion of matters of mutual interest will normally last from one to two weeks and provide for visiting groups of four to eight specialists. A programme of reciprocal visits covering the fields of collaboration was drawn up during the discussions and the first visits will take place later this year, says the AEA.

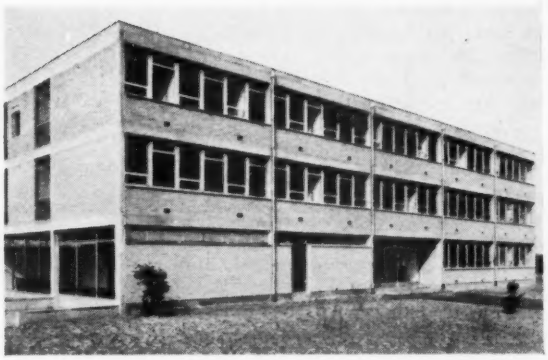
The USSR representatives at the talks, which took place on May 15 and 16 were: Professor V. S. Emelyanov; Mr K. D. Sinelnikov, Director of the Physico-Technical Institute of the Academy of Sciences of the Ukranian S.R. and Mr A. I. Leipunski, Scientific Director of the Physico-Energetics Institute of the State Committee.

The UK representatives who took part in these talks were: Sir Roger Makins; Sir William Penney, Deputy Chairman of the Authority; Sir William Cook, Authority Member for Reactors; Sir John Cockcroft, Part-time Member of the Authority; Dr F. A. Vick, Director of the Research Group of the Authority and of A.E.R.E., Harwell and Dr T. G. Pickavance, Director of the National Institute for Research in Nuclear Science.

Professor Emelyanov, accompanied by Sir Roger Makins, called on the Minister for Science, Lord Hailsham, on May 16. From May 17 to 19 members of the Soviet delegation visited the Authority's research establishments at Harwell and Winfrith and the nuclear power station which is under construction for the Central Electricty Generating Board at Hinkley Point.

• **United Kingdom** The AEA has a five year plan for extending the processing facilities at the radiochemical centre at Amersham and they propose to continue and extend their vigorous sales and customer service activities, the House of Commons was told recently.

• **OEEC** Dr M. Higatsberger, executive director of the Austrian Atomic Energy Agency, and chairman of the DRAGON general purposes committee, told a press conference in New York that DRAGON should be ready for operation in the middle of next year.



EUROCHEMIC PROGRESS A view of the completed administrative building for the European Nuclear Energy Agency's Eurochemic project. Work on the Eurochemic fuel reprocessing plant was officially inaugurated on July 7, 1960, and present plans envisage tests runs for the plant in 1963 with full operation during 1964

Emelyanov calls for more international research

London A call for common international programmes on nuclear research was made by Professor Vasily Emelyanov, chairman of the Soviet Government's Atomic Energy Committee in an exclusive interview with *Nuclear Power* recently.

'I think it's important now to prepare common programmes', he said. 'For instance, with fast reactors, everyone is carrying out research — France, Britain and America. It should be possible and it is reasonable, to collate all scientists and prepare a common programme. We will not spend so much money and we will get quicker and better results. This will be so because we will have all the scientists together and the results will be good because it will be discussed with all concerned. We have many such problems — one country could take a certain sphere of work and others another and together work out the whole problem under this common programme'.

Professor Emelyanov, who was speaking shortly before his departure after a week in the UK during which he signed the Soviet-UK nuclear agreement, said it was unlikely that he would return to the UK this year. However, he was taking away with him a favourable impression of UK work.

He had been very impressed with the work at Winfrith which had been developed in such a short time. 'You have collected there a lot of very good and very young scientists and your way in science is very different and very interesting.' Professor Emelyanov added.

Asked about the 50 MWe Soviet fast reactor on which design work had been completed (See *Nuclear Power*, February, p 75) Professor Emelyanov replied: 'This design study has been completed but I do not know whether (the reactor) will be built now. We will probably decide on a new reactor. In my opinion, it is unnecessary to build such small reactors as they are too expensive. We are conducting fast reactor research at our Obninsk reactor and after this is completed we will have a discussion on what it will be possible to develop.

'I would point out that Russia is in no hurry to develop nuclear power — this, of course, does not mean that we should stop work — but we have plenty of oil, water and coal. We will wait until the results of our present (overall) programme are complete (before deciding on the further development of promising types).

'We expect our two stations (Voronezh and Ulyanovsk) will be completed next year; the Czech station will be completed in 1964-65 and the East German about the same time. These are all different types'.

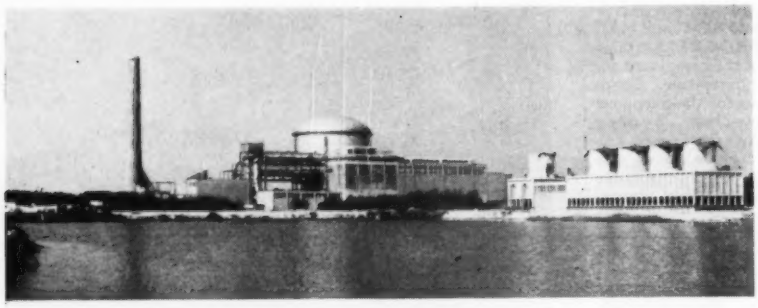
On the East German station, Professor Emelyanov said that he had had discussions with the East Germans as to the need for building two reactors for their station (Neuglobsaw). For a prototype, it was unnecessary to build two reactors of the same kind and he did not think this would now happen.

Asked about Soviet progress in the use of organic coolants, Professor Emelyanov stated: 'We recently put into operation a small organic cooled reactor of about 250-300 kWt and we are starting to study different organic coolants. I think its a possibility for ships but of course there are different opinions.'

• **USSR** Soviet specialists are being sent to Iraq to help build a research reactor at Baghdad, according to Moscow Radio. This follows a contract signed in Iraq for an isotope laboratory and other facilities.

• **France** Sea trials of the first French nuclear-propelled submarine would take place by 1967-68, according to Admiral Georges Cabanier. France, he said, hoped to build three atomic submarines.

WORLDVIEW



BELGIUM'S BR-2 REACTOR This high flux materials and engineering test reactor, BR-2, at Mol, is scheduled to go critical at the end of June. The beryllium core matrices for the 50 MWt reactor were made by Brush Beryllium Co of the USA

• **USSR** The Soviet-Ghanaian agreement on co-operation in the peaceful uses of atomic energy has now come into force. The agreement was initialled in Moscow on February 28. Ghana has no direct agreement with the UK.

• **Italy** From 1970, nuclear energy may become competitive in Italy, according to Sig. Vittoria de Biasi, vice-chairman of Edisonvolta (Milan) in a recent speech.

• **IAEA** The text of a draft convention on minimum international standards regarding civil liability for nuclear hazards has been completed by an intergovernmental committee. It will be submitted to the IAEA Board of Governors for appropriate action.

OVERSEAS

Further subsidies planned for US reactors?

Washington Additional financial incentives to American industry to assure construction of additional power reactor prototypes are being considered by the USAEC.

Speaking before the Joint Committee on Atomic Energy on the AEC's authorization bill for appropriations, Dr Glenn T. Seaborg, the AEC chairman, said AEC staff had been studying 'various types of incentives such as a capital grant, operating subsidy, modification of prices and charges for nuclear materials, fast tax write-off and financing of long transmission lines. As yet we have not reached a conclusion on this important and complicated matter. During the coming months, we will expand our studies and discuss the problem with members of the nuclear industry and with this Committee. If we determine that financial incentives can give us the programme we need to move ahead toward our national objective, we will make appropriate proposals to the Congress as part of our 1963 fiscal year authorization request'.

Dr Seaborg added that there was a possibility that additional financial incentives would not suffice. In that case, it might be even more necessary to consider the possibly more expensive approach of a programme under which the Government would construct and initially operate these prototype plants which were needed to reach the country's goals.

'Under this approach, Dr Seaborg continued, 'the Commission, using fixed price competitive bidding among private contractors, would construct complete plants on publicly or privately owned utility power grids; the utility would operate the plant and buy electric power from the plant for a fixed period at some predetermined rate developed under competitive proposals from utilities. At the end of the fixed period, the utility would be committed by contract to purchase and the Government to sell the plant at a price which will allow it to compete with conventional plants of the same size.'

AEC disappointed Experience over the past two years in the co-operative prototype demonstration programme had been disappointing, the AEC chairman added. In the spring of 1959, the AEC had planned that four reactor prototypes should be constructed. Only one, the 50 MW high power denisty BWR at Big Rock Point, Michigan (Consumers Power Company) was under construction. The 50 MW OMR was not accepted by privately owned utilities; the 20 MW small power reactor and the 50 MW BWR were both accepted but siting problems caused the companies to withdraw.

The AEC had again issued invitations for the OMR prototype and expected that construction would begin early next year. The Commission had been advised by a utility of its interest in the 50 MW BWR and there was some interest in the 20 MW PWR.

Turret reinstated Meanwhile, the TURRET high temperature project had been reinstated. An earlier decision to cancel the project has been reversed. The proposed authorization bill now provides $3.5 million for ultra high temperature reactor experiment buildings to house the TURRET project at Los Alamos.

The decision to drop the TURRET high temperature gas-cooled reactor experiment was announced by the AEC in February. It was then said that other reactors would be used for the experiments and studies.

The AEC's authorization bill asks for money for the following new projects: electric generating facilities for the Hanford New Production Reactor; the experimental beryllium oxide reactor; experimental organic cooled reactor loops and TURRET.

Sweden studies pressurized heavy water reactor

New York A technical evaluation study of a 250 MW pressurized heavy water reactor is to be undertaken for AB Atomenergi of Sweden by Westinghouse Electric International Company in collaboration with the A. Johnson Company of Stockholm and the Betchel Corporation of San Francisco. The joint study is to be completed in eight months and forms part of Sweden's nuclear programme for 1961.

A team of eight Swedish engineers and physicists, four from AB Atomenergi and four from the A. Johnson Company, will be in the United States for the duration of the study. Six have already arrived and two others are expected shortly.

The A. Johnson Company, whose atomic group is undertaking its share of the study, also has extensive operations in iron and steel, oil refining and shipping.

The Swedish team is made up of Bryan McHugh, Ingvar Holtz, Kalle Engelberntsson and Gunnar Andersson of AB Atomenergi, and Aldor Jonsson. Lennart Wall, Svenlof Sandberg and N. Ekroth of A. Johnson Company.

Canada to decide soon on OMR

Toronto Atomic Energy of Canada Limited is shortly to make a decision on whether to proceed with detailed design and perhaps construction of a 30-40 MW organic cooled heavy water moderated experimental reactor. Mr J. L. Gray, president of AECL, told the first annual meeting of the Canadian Nuclear Association that this followed the recent completion, under contract to AECL, of a preliminary design and cost estimate for the OMR by Canadian General Electric.

On other Canadian power projects, Mr Gray pointed out that the 20 MW NPD station was expected to go critical late this year with full power operation expected about May, 1962. The 200 MW Douglas Point Nuclear Generation Station with its CANDU reactor was well under way.

Speaking on the role of private firms in Canadian nuclear plans, Mr Gray said it was to be regretted that 'the parent companies of some of our Canadian fabricators have decided to take all the economic risks they can afford in their home territory. . . . Investment in Canada by private companies is quite insignificant. I do not find serious fault with this attitude up to the present time but I do feel that we are fast approaching the time when the Canadian commercial world must take some financial risks if it is to taste the potential financial gains which seem probable within five to ten years.

Ontario expected to install 1000 MW of nuclear capacity out of the 4·8 million kilowatts of new capacity which the province expected to install by 1970 or 1971, the Minister of Energy Resources for that province, Mr R. W. Macauly told the meeting. By 1980, Ontario expected to have a total nuclear capacity of about six million kilowatts.

Mr P. K. Peterson, Orenda Engines Ltd, said it would be wise to study the enriched uranium market and to examine carefully the gas centrifuge process as a means of entering it. It was understood that a government agency had been designated to study the various aspects of enriching uranium in Canada and that AECL had recently acquired the rights to promising US patents in the gas-centrifuge field, he said.

Nevertheless, the possession of one of the largest reserves of uranium ore in the world and the intense interest in the process that is being shown by other countries, notably the USA, Holland and Germany, did surely warrant a careful look to ensure that Canada did not end up as an 'also ran' in the uranium race when nuclear power became competitive.

Indian Point PWR goes critical this December

Washington December is the month in which the 151 MW Indian Point PWR is expected to go critical, an AEC hearing was told recently. Mr James Fairman of Consolidated Edison Co. of New York, the owners, told the hearing that non-nuclear testing of the plant equipment would start in August and be finished by the end of October. Fuel elements would begin to arrive early in October and criticality should be reached in December.

The hearing was held to seek approval of the final design of the station.

The plant has a pressurized water, thorium-uranium core reactor with a heat output of 585 MWt. It will produce a total electric output of 275 MWe of which the reactor will provide 151 MW and superheaters 104 MW. Cost of the plant is put at $110 million.

• **United States** On July 1 the AEC will reduce its base charges for enriched and depleted uranium from 20 per cent for highly enriched through about 40 per cent for natural to 63 per cent for depleted uranium. The use-charge rate goes up from 4 per cent to 4·75 per cent.

• **United States** The AEC is inviting co-operatively owned and publicly-owned utilities to submit proposals for participation in a prototype 50,000 net electrical kW OMR project.

• **Brazil** The President has approved a plan for construction of a nuclear power station which would supply electricity to north-eastern or nothern Brazil.

• **USSR** The Kirov works in Kharkhov, in the Ukraine, has completed the first 70 MW steam turbine set for the Novo-Voronyezh nuclear power station.

• **United States** The supreme court has reversed the judgment of the Court of Appeals in setting aside the order issued by the AEC confirming the provisional construction permit for the Enrico Fermi Fast Breeder reactor.

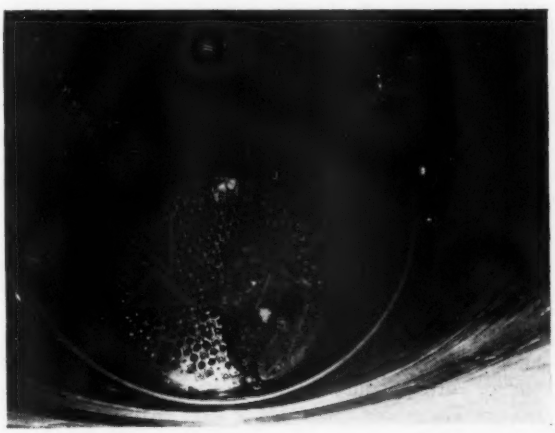
The AEC drops gas-cooled project

Washington Co-operative plans to build a gas-cooled heavy water moderated power reactor are being ended by the AEC. The reason is said to be technical and economic uncertainties.

An announcement by the AEC said in order that the companies concerned — the East Central Nuclear Group and the Florida West Coast Nuclear Group — should continue their interest in the atomic energy programme, the Commission had proposed that they consider means to continue their exploration of natural uranium systems of mutual interest.

The present actions follow a proposal submitted by the companies on February 14, 1961. This provided for continuation of the present development programme to the end of 1962 and deferment until that time of consideration of a firm committment by the utilities to construct the plant.

The research and development programme for the 50 MW plant was reoriented in August, 1960, to take in development of beryllium-clad fuel elements. After discussions, the companies hoped to submit a revised proposal by January 1, 1961 which would offer greater assurance that the plant be built. However, difficulties led to the conclusion that it was not feasible to make a commitment on plant construction until these uncertainties were clarified by further research and development. Under the current contract, the AEC and the companies share the R & D costs.



HALLAM PRESSURE VESSEL Inspection of the underground stainless steel vessel which will house the 75 MW reactor for the Hallam nuclear power plant is being carried out. The vessel is 33 ft deep, 19 ft in diameter and weighs 50 tons. The sodium-cooled, graphite moderated reactor is expected to go critical this autumn

The first of the plutonium-producing magnox reactors will start up this summer and a solution to the problem of burning plutonium needs to be found in the next few years

The use of plutonium in reactors

by M. B. WALDRON, Ph.D., B.Sc., Leader of the Plutonium Metallurgy Group, AERE, Harwell

THE FIRST PUBLISHED KNOWLEDGE of plutonium was largely concerned with the pure metal and its concentrated alloys. A large part of this information was declassified before the first Geneva Conference on the Peaceful Uses of Atomic Energy, at which Russian developments were also reported, and this information was reviewed by Coffinberry and Waldron (*1*). At that time it was clear that, apart from a few phase diagrams of interesting alloy systems and an accumulated experience of how to handle and fabricate materials containing plutonium, there was little knowledge of possible fuels. In America and Britain the present state of fuel element technology is therefore based on about six or seven years of directed research. The French effort in this field did not get under way until some two years later although they presumably benefited considerably by the published experience of their precursors in the field.

In assessing the fruits of these activities, allowance must be made for the difficulties introduced by the radioactive toxicity of plutonium. The maximum permissible body burden for plutonium is set by international agreement at 0·3μg, and such a low limit entails the use of very efficient enclosures, or gloveboxes, for all research, development and production work, thus increasing considerably the time taken to complete any given investigation. It also limits very severely the places where such work can proceed. Furthermore, whereas much uranium fuel technology has been carried out in normal industrial plant using temporary precautions against the relatively small radioactive hazards involved, work on plutonium fuel has to be restricted to specially constructed plants and they must be fully equipped for the range of processes involved. There can be no question of hiring a works rolling mill or extrusion press for a special shift operation on plutonium bearing materials.

While handling restrictions are considerable at the research and development stage, they are not so great in production, provided that the processes required can be clearly specified and a fully automated plant designed to carry them through. Apart from the development charges, the fabrication costs for plutonium fuels are therefore not likely to be very much greater than for corresponding uranium fuels, despite the hazards involved. The precise magnitude of these increased costs will depend greatly on the nature and number of the manufacturing operations. The assessment of the process developments that are required is under study in many places. One outstanding example is the elaborate Fuel Fabrication Facility at the Argonne National Laboratory (*2*), while less sophisticated but possibly more versatile facilities are being operated or installed elsewhere in the United States and the United Kingdom.

Current national reactor programmes and plutonium research efforts show several promising lines of development. Plutonium can be used in fast reactors, or thermal reactors requiring slight enrichment. In the latter the plutonium can be either spread uniformly or concentrated in small 'spike' elements. The plutonium-fueled fast breeder reactor has an especial economic attraction and in the UK designs for a prototype fast breeder are being prepared. Work is being done on the problem of swelling in metal fuels and the future importance of alloy fuels will depend on the success of these studies. A large amount of the work on plutonium in the future will be concerned with mixed oxides, carbides and cermets.

Although the radioactive hazard of plutonium is of consequence in the development and manufacture of a fuel, it does not contribute materially to the safety problems connected with reactor operation. This is because the hazard due to the α-activity of the plutonium in the fuel is negligible compared with the fission products activity produced in the fuel after a modest burnup.

The use of plutonium in power reactors will therefore depend upon the economics of the whole cycle, taking into account separation, fabrication and recycling costs, breeding ratios, investment costs, and so forth.

The use of plutonium can be envisaged in both thermal and fast reactors. Its use in thermal reactors would simply be as a means of providing the slight enrichment needed in more advanced designs to enable the fuel to go to a higher burnup without excessive loss of reactivity and to offset neutron losses through alloying additions to the fuel or changes in can design.

In all such cases, the cost of enrichment, including fabrication and processing, must be balanced against the financial return from the increased burnup or other advantage that results. It is also necessary to consider the relative merits of enrichment by plutonium against the use of uranium enriched in U-235; whether it is better to set up chemical separation plants for plutonium rather than diffusion plants for enriched uranium; whether the physics parameters and metallurgical behaviour are satisfactory; and so forth.

A further important decision is whether to distribute the plutonium enrichment uniformly through the fuel charge, or concentrate it in a relatively small number of 'spike' elements that probably would be distributed in special channels. Spike enrichment has the possible advantages of reducing the number of elements which would need fabrication and reprocessing under special conditions, while at the same time allowing a design and composition of spike fuel element to be selected to give the higher burnup required. Against this must be balanced the additional complication in design to allow for special channels and separate discharge of the spike elements, the provision and operation of separate production and processing lines for the spike fuel, and the physics effects of the non-uniform nature of the charge.

In the fast reactor field, plutonium fuels have an incentive of their own, deriving from the high breeding gain with plutonium in a fast flux. Thus, the economic breeding ratio for practical fast reactor concepts commonly range between 1·3 and 1·8. The problems of plutonium utilization in these reactors therefore are concerned mainly with the rigorous requirements of the highly rated compact core and the economics of such systems compared with advanced thermal reactor concepts. In the choice of fast reactor fuels, as with spike thermal fuels, a relatively high fissile content provides an opportunity for the development of metallurgical structures that is denied for a uniformly enriched thermal core. Also, the lower cross-sections for fast neutrons permits a wider choice of inert diluents or alloy additions. It is therefore possible to find a fairly wide range of alloys, cermets or ceramics which show promise of providing adequate irradiation stability at the high ratings and fuel temperatures that are required. The economic success of the fast reactor cycle will depend upon the balance between the advantages of high breeding ratio and compact core size (which tends to lower capital cost) and the increased fuel cost resulting from the special engineering requirements coupled with the complications of plutonium handling.

Having thus reviewed the factors influencing the development of plutonium fuels for power reactors, it is appropriate to survey current reactor developments before describing the research programmes on materials that will support them.

CURRENT REACTOR PROGRAMMES

United Kingdom

The current series of civil reactors based on magnesium-canned natural uranium fuels do not appear to offer great attractions for enrichment either by plutonium or U-235. To do so would involve large capital investment in special plant which would only be justified by a major advance in their performance. The next round of reactors is likely to be based on the AGR design in which UO_2, slightly enriched, would be canned in stainless steel or beryllium, gas cooled. In this case, it is quite feasible metallurgically to use plutonium for slight enrichment of the UO_2 (approximately 1% plutonium). This development would involve little modification of the manufacturing routes, since automation of the processes easily looks after the small concentrations of plutonium involved; nor would the irradiation and general metallurgical behaviour of the fuel element be significantly affected. The advantages of using plutonium in this way *vis-à-vis* U-235 are marginal and little effort is being devoted in the UKAEA to this possibility.

The most attractive use of plutonium in thermal reactors is in the high temperature reactor concept. In this reactor concept the fissile material is dispersed in a refractory medium acting as moderator, capable of withstanding high temperatures and burnups. The most highly developed fuel element designs are centred on enriched uranium dispersed as carbide in a graphite base. Dispersions of uranium oxide in refractory oxides such as beryllia are also being studied for more long term use. In all these cases, the substitution of plutonium seems possible. These reactors promise to give high fuel ratings and thermodynamic efficiencies at relatively low capital cost and hence are competitive in many ways with the fast reactor concepts.

The Dounreay Fast Reactor, DFR, is intended to provide experience in the operation of a fast reactor and to irradiate advanced types of experimental fuel elements in a fast flux. The main charge however is not plutonium based. The formative stages have begun on a project to develop a prototype fast reactor of several hundred megawatts capacity, charged with a plutonium fuel. Several promising types of fuel, metal cermet and ceramic, are under consideration at the present time and the various possibilities are detailed in a later section of this paper.

United States

In America, there are a relatively large number of reactor proposals which could employ a plutonium fuel but the availability of low cost enriched uranium has diminished the incentive to develop a definite programme for plutonium utilization. However, one thermal reactor project, the Plutonium Recycle Test Reactor situated at Hanford Works in the State of Washington is now well under way and there are three fast reactor projects which involve plutonium, EBR2 which is the responsibility of the Argonne National Laboratory, Enrico-Fermi at Detroit and LAMPRE at Los Alamos.

The PRTR project is essentially aimed at studying the reactor physics aspects of recycling plutonium through a reactor operating at about 100 MW power level (*4*). In support of this, however, there are extensive facilities for the fabrication of plutonium fuels and the recovery and reprocessing of the plutonium. The emphasis in fuel development has been twofold, firstly the provision of a reliable driver-charge and secondly the development of cheap methods of producing plutonium fuel elements.

EBR 2 is a 60 MW (thermal) experimental fast reactor (*5*) which will be mainly fuelled by uranium charges but in which plutonium bearing fuel elements will be studied. At the Argonne, there are extensive facilities just being completed for both basic studies and fabrication trials. The fabrication facility, already mentioned, is a very large, integrated system of glovebox lines feeding into a main conveyor belt, each process being highly mechanized.

The Enrico-Fermi reactor is a 300 MW experimental reactor (*5*) which will be uranium fuelled. No plans have been announced for plutonium fuelling of this reactor although

their technical staff have widely contributed to discussions of plutonium fuel research.

LAMPRE represents a very different approach to plutonium utilization in the fast reactor field (*6*). It is a small experimental reactor (1 MW) in which a very highly rated molten plutonium alloy is held in tantalum tubes. It is a concept which is not only unusual but which takes advantage of the low melting points that can be achieved in plutonium-bearing alloy systems. At Los Alamos there are extensive facilities for research and development of plutonium in all its forms.

Canada

Apart from experimental irradiations, particularly of a dilute alloy of plutonium in aluminium, the AECL at Chalk River have not hitherto put much effort into plutonium utilization in reactors. However, they have always maintained a small and very efficient plutonium research team which has studied plutonium-aluminium alloys, plutonium intermetallic and ceramic compounds and manufactured actinide-beryllium neutron sources. They are now commissioning a large plutonium laboratory and increasing their effort in this field.

France

The French have a small but vigorous Fast Reactor project centred round an 10 MW (thermal) experimental reactor RAPSODIE (*7*). The emphasis in this reactor is on demonstration of breeding in a self-sustaining system, the fuel problems being simplified by adherence to a low coolant temperature, and consequently low fuel surface temperature. The plans for fuelling this reactor are keyed to both a ternary uranium-molybdenum-plutonium alloy charge and PuO_2–UO_2 charge, canned in stainless steel.

In support of this reactor, there is a well established plutonium laboratory at Fontenay-aux-Roses, near Paris and a new establishment at Cadarache which is being equipped for the fabrication and post irradiation testing of the RAPSODIE fuel elements.

Russia

Three fast reactor experiments have been announced by Russian scientists, BR-5, a 5 MW PuO_2/stainless steel fuelled low power assembly, BN50 and BN250 of 50 and 250 MW (thermal) output which are supposedly plutonium fuelled but about which no details are known to the author.

It is clear from contacts with Russian scientists at Geneva and from their published papers that an effort at least comparable with that in the United Kingdom or the United States is devoted to studies on plutonium. At present, this published work has all been in the general field of basic research on the physical properties and alloying behaviour of plutonium metal, so that no evidence is available on which to judge their progress in plutonium reactor technology.

FUEL MATERIALS

Basic requirements

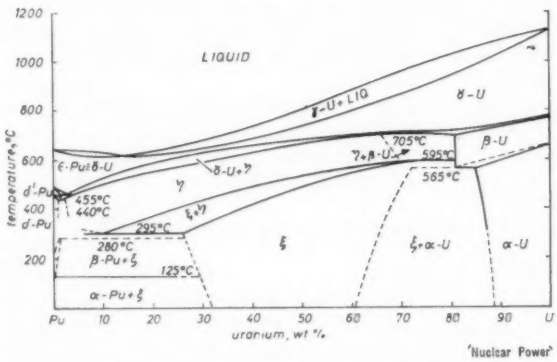
It has already been mentioned that the compactness of the highly rated fast reactor core imposes rigorous requirements on the fuel. It needs to be capable of withstanding a high burnup to avoid over-frequent discharging of the fuel. It must stand a relatively high centre temperature and must be compatible with can and coolant. Breeding from a self-sustaining fuel is desirable if reactivity changes are not going to be a large problem, requiring an overall ratio of fissile to fertile atoms of about 1 : 9. If the investment is to be reasonable, a high fissile density is necessary. These criteria would lead to an alloy containing 10–30% plutonium, depending on the diluent, or cermets and ceramics containing a similar percentage of the metal atoms as plutonium. It is therefore necessary to review possible systems for materials having desirable metallurgical and irradiation behaviour in this range of plutonium contents. Although diluents which markedly degrade the neutron spectrum are to be avoided, the restrictions are much less than for thermal systems.

For the latter systems, fuel elements for spike enrichment will be found among the group of materials of interest to the fast reactor, save that neutron absorption cross sections will seriously limit the choice of diluent, although the conditions of service may be somewhat less rigorous. Uniform enrichment of thermal reactors clearly is limited to small additions of plutonium to such well known fuel materials as uranium metal, UO_2 and dispersions of UO_2 or UC in graphite, beryllia etc.

Alloy fuels

The plutonium-uranium alloy system is of evident relevance to plutonium utilization. It has been studied by the USA, USSR and UK who agree on the essential features of the system. Figure 1 shows one form of the diagram, from which it can be seen that up to 10% plutonium has little effect on the phases present except a lowering of the temperatures of the phase changes, which would reduce the permissible centre temperature of the fuel. One can therefore see that uniform enrichment of uranium metal for thermal reactors (~1% Pu) would be unlikely to cause major metallurgical problems, although it may affect, advantageously or otherwise, grain refinement and preferred orientation effects on growth, wrinkling or swelling. At higher compositions, relevant to the fast reactor and to spike enrichment of thermal reactors, the occurrence of the embrittling zeta-phase makes the binary alloys unsuitable, in addition to the lowered transformation temperatures.

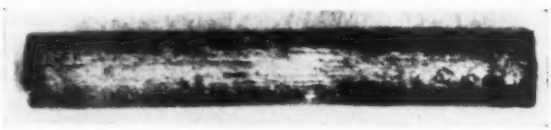
However, uranium-12 wt% molybdenum alloys are well-known for their superior resistance to growth wrinkling and swelling damage because of cubic gamma-uranium structure which is retained to room temperature in this alloy. Studies at Harwell and Fontenay-aux-Roses have shown that plutonium can be substituted for uranium in this alloy up to more than 20% Pu without losing the desirable metallurgical properties of the binary alloy. Irradiation tests are in progress in both countries to establish the limiting burnup at which



The plutonium-uranium system (Fig. 1)

serious swelling occurs. Work on binary uranium-molybdenum alloys suggest a limit of 2% burnup at 600°C dropping to 0·5% at 800°C for such fuels at the present time. An alloy with 10% Mo 20% Pu has been proposed for the French experimental fast reactor RAPSODIE (*7*). For thermal reactors it is doubtful whether such a high molybdenum content would be acceptable, even for spike elements.

A related type of alloy is under study at the Argonne in connexion with EBR2, in which the equilibrium fission product composition remaining after the high temperature reprocessing cycle are deliberately left as alloying additions. This alloy known as 'fissium' has been shown to have improved irradiation stability compared with unalloyed uranium particularly at temperatures below 600°C but this improvement is not so marked in the presence of plutonium (*8*). Experimental plutonium-bearing fuel elements will however probably be irradiated in EBR2.



A specimen of a 40 at.% Pu in zirconium alloy which has been irradiated to 0·8% burnup x 8 (Fig. 2)

Among the remaining alloy systems reported in the literature, only three emerge so having any promise as solid fast or spike fuel materials, alloys with zirconium, thorium or iron.

An alloy with 40 at.% Pu in zirconium is single phase face-centred-cubic up to about 600°C and body-centred cubic above 600°C. This has been shown to have good irradiation behaviour at 500°C (*9*) as shown by the specimen in Fig. 2, which had been irradiated to 0·8% burnup. This behaviour may well continue at higher temperatures. The alloy might be suitable for spike thermal enrichment, or as a burner fuel in a fast reactor. For self-sustaining fuels, ternary zirconium-plutonium uranium fuels might be studied but it is unlikely that a favourable combination of fissile content and U/Pu ratio could be achieved.

Thorium alloys containing up to 15% plutonium have been shown to have good shape stability under irradiation but did suffer from an isotropic swelling equivalent to unalloyed uranium (*9*). It would thus be necessary to improve the latter property for these alloys to become attractive, either by creep-resistant additions or by controlling fission gas bubble nucleation.

Iron-plutonium alloys containing less than 5 at.% plutonium have a microstructure consisting of the strong compound $PuFe_2$ dispersed in a continuous matrix of iron. Such alloys have been shown to have good irradiation stability as would be expected by analogy with other dispersion type fuels such as cermets (*10*). It would only have value as a possible burner fast reactor fuel, in competition with a stainless steel cermet, its principal advantage being that it can be cast and fabricated by normal metallurgical techniques and that its melting point is about 1000°C. It may be regarded as a high temperature analogue of the well-known aluminium based alloy used in materials testing reactors such as DIDO, in which UAl_3 is dispersed in an aluminium matrix. A comparable series of plutonium aluminium alloys exist and these have been used for experimental irradiations in water cooled reactors both at Chalk River, Canada and Hanford, USA. However, the low melting point of these aluminium based alloys, 625°C, limits their usefulness for other reactor applications.

One further class of metal fuel has been mentioned in connexion with the LAMPRE liquid metal fuelled reactor experiment. For this use has been made of the plutonium-rich eutectic with iron which melts just above 400°C and contains 10 at.% Fe (*11*). This highly concentrated fuel is suitable for a small reactor experiment of this kind, but for a large scale version, some dilution of the plutonium would be necessary. Work at Los Alamos and at Harwell has established that a series of ternary alloys exist containing plutonium, rare earths and transitional type metals which give melting points around 415°C over a wide range of plutonium contents. One particular such alloy is the ternary eutectic composition 4% Co 23·5% Pu. Before these fuels can be extensively developed, many problems concerning compatibility and behaviour of a molten metal under irradiation need to be solved.

Ceramic fuels

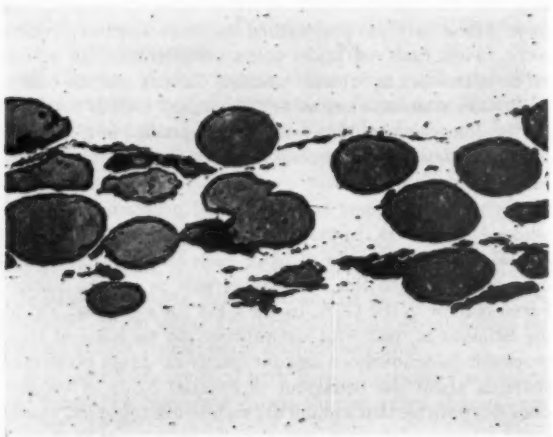
Ceramic fuels have the well known advantage of gaseous fission product retention without swelling up to relatively high temperatures, somewhat offset by a low fissile density and, in the case of oxides, low thermal conductivity and thermal shock resistance. The oxide fuels have hitherto attracted most attention although great interest is now being shown in carbide fuels. These have not yet reached the same stage of development. Oxide fuels are under active consideration for a wide range of reactors in Britain, America, Canada and the USSR. In Britain, stainless steel or beryllium clad UO_2 is proposed for the AGR which could in principle be enriched by plutonium if the economics and plutonium supply position warranted this. Mixed plutonium-uranium oxide fuel is also proposed for PRTR charges and there is a substantial programme of work planned by NUMEC in the USA for testing in existing experimental reactors. The use of oxide fuels for fast reactors has been considered in this country, as well as for the Enrico-Fermi reactor in the USA, by the CEA for RAPSODIE, and by the Belgians at their Mol laboratories. So far none of these proposals have advanced very far, partly no doubt because of anxieties about the behaviour of cracked oxide in sodium, since it is possible that sodium drawn into a crack at low power could become vaporised with consequent damage to the fuel element when the temperature inside the fuel exceeded the boiling point of sodium. Studies in support of all these proposals have shown that additions of plutonium improve rather than lower the sinterability of UO_2. Larger additions lead to slightly decreased stability of the oxide although this is not likely to be a serious disadvantage. One particularly interesting aspect of these solid solutions is that non-stoichiometry in PuO_2 is in the direction of the lower oxide Pu_2O_3 whereas UO_2 show non-stoichiometry only in the direction of the higher oxides. At proportions around 25–50% PuO_2, however, these effects only modify in detail the fabrication route for the oxide pellets and are unlikely to affect the fuel element behaviour under operating conditions.

The use of carbide fuels has the twofold advantage of a higher fissile density than oxide and a thermal conductivity comparable with uranium metal. The latter leads to thicker fuel element sections for a given temperature rise and is associated with enhanced resistance to thermal shock. Much

work is being put at the present time into the production of crack-free carbide in massive form, by both casting, plunge sintering and conventional powder techniques. In parallel with this, work on the properties of carbide solid solutions between PuC and UC is being undertaken at Harwell and Dounreay in the UK, at ANL particularly in the USA and at Fontenay-aux-Roses in France. This work should enable any success with uranium carbide fuels to be quickly extended to mixed carbides containing plutonium.

Dispersion fuels

The fuels so far discussed have been alloys or solid solutions containing plutonium but there are two other alternatives generally described as of the dispersion type. In these, a ceramic phase containing the fissile atom is dispersed in an inert diluent whether metal or ceramic. The fissile ceramic must be unreactive with the matrix at the operating temperatures and the matrix must not be susceptible to serious changes in properties under irradiation. The metal based cermets have so far received most attention and are very promising fuel materials, combining the gaseous fission product retention of the ceramic particles with good conductivity and ease of fabrication resulting from the metallic matrix. Most work has been done on stainless steel cermets containing 20–30 vol.% UO_2, and little difference in behaviour would be expected if the UO_2 was partially replaced by PuO_2. Figure 3 shows a



Section through a cermet showing uniform dispersion of rounded oxide particles in a metal matrix, x 56 (Fig. 3)

section through such a cermet, illustrating the uniform dispersion of the rounded oxide particles in a metal matrix. Such a fuel would have applications where a high integrity high burnup fuel were required, as for example, in a ship propulsion reactor or military reactor. The enrichment needed to offset the substantial neutron absorption in the stainless steel would however make the reactor not very attractive economically for thermal reactors. For fast reactors, such a fuel is very attractive but the relatively low proportion of ceramic phase would require a large investment and would not permit the fuel to be fully self sustaining. Considerable research is going into the development of high ceramic fraction cermets. As the metal content is decreased, its function changes from that of a restraining network to being essentially a thermal conduction and bonding medium. The point at which this transition occurs is an important study from the point of view of fuel element design. Current research in the UK and the USA covers such aspects as spherical ceramic particle production, metal deposition, and the relation between structure and mechanical properties or irradiation behaviour.

A further development of the cermet concept (*12*) is to replace the steel matrix by the uranium-12 wt.% molybdenum alloys, thus permitting the simultaneous achievement of a, high fissile density and a self-sustaining fuel. In this case the matrix would be subject to damage by fast fission of the uranium, but before this reached serious proportions, a considerable burnup of the ceramic phase would have occurred. This concept will need considerable development before it could be used with confidence in a reactor charge however.

Other developments of cermets include the substitution of carbide or nitride for the ceramic phase and the development of refractory metal matrices. The use of carbide or nitride would enable a useful increase of fissile density to be achieved. However attention would have to be paid to the possible reduced stability of plutonium containing carbides, particularly in compatability with the matrix, and to the manufacture and behaviour of nitrides.

Dispersions of fissile oxides in ceramic diluents such as beryllia to give a high temperature stable element are being studied. Such developments would have relevance to both high temperature reactors and fast reactors.

PRESENT STATUS

This review has shown that utilization of plutonium in reactors is possible in a variety of ways, the precise choice being likely to depend on a number of factors which will vary from one country or project to another. In this country plutonium will be produced in the present round of civil reactors and the alternatives for utilization seem to be in the more advanced concepts such as fast reactors or possibly developments of the HTR system. In the USA, the incentive to use plutonium enrichment is less urgent because of the greater availability of other sources of power and of cheap U-235. We may therefore expect to see several years of intensive research on the more promising fuel materials before the need to finalize power reactor designs will require a firm selection to be made. Much of this effort will undoubtedly go to mixed oxide fuels, to carbide fuels and to cermets. Whether alloy fuels will continue to attract attention will largely depend on the success attending present studies on the general problem of swelling in metal fuels. At the present moment, one can safely say that there are a number of satisfactory solutions open to the reactor engineer.

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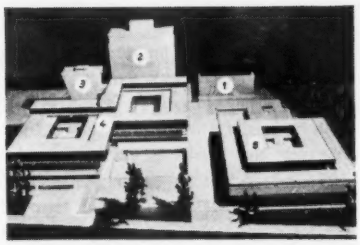
Government grants of over £1 million to equip Oxford University with a 20 MeV accelerator will facilitate research into the whole periodic table.

New Nuclear Research Centre for the UK



Oxford University's new Science Precinct includes: a Metallurgy building 1- completed in 1960 at a cost of £100,000, a nine-storey Engineering building 2-under construction, Nuclear Physics research laboratories 4- with generators 3- to be completed mid-1964, and a Teaching and Theoretical Physics building which includes a lecture theatre to seat 800 -5 (Fig. 1)

WITH THE COMPLETION of the new nuclear physics research centre at Oxford in 1964 and the provision of high energy equipment, making it possible to carry out experiments throughout the whole range of nuclei, Professor D. Wilkinson, FRS, will be able to start on his programme of long-term research on nuclear structure. Studies will include the interpretation of 'stripping' patterns in the heavy elements, radiative capture of protons in the 'giant resonance', important endothermic reactions in the light elements to determine the distribution of 'hole states', and reactions induced by heavy bombarding particles, such as ions of oxygen.

Oxford's requirement for a 20 MeV proton beam with the additional properties of energy homogeneity, continuous and separate control of particle energy and beam intensity, and good collimation, will be met by injecting negative ions at energies of 8-10 MeV into a horizontal tandem generator with an eventual total output of 20MeV. A further requirement was for a machine that could also operate as an independent electrostatic generator. The injector to be built is basically a large vertical electrostatic generator of conventional type with a pressure vessel, 13ft dia × 40ft long, designed to withstand a pressure of 17 atmospheres (Fig. 2).

The stack of equipotential plates consists of two columns; the lower is 12ft long × 6ft 6in dia, the upper is 8ft long × 5ft dia. Two large shells arise from these columns the smaller of which, 5ft dia × 9ft 6in high, houses the ion source, whilst the large one, 8ft dia × 20ft high, serves to smooth out the variation of electrostatic field between the inner terminal and the outer pressure vessel. Fully pressurized, the weight of gas in the vessel is four tons.

The two different project requirements have resulted in distinctive design features. Used as an injector the generator delivers beams of elements capable of forming negative ions — hydrogen, oxygen, sulphur, etc. As an independent machine, it supplies positive ions in greater quantity over a wider range of elements than negative ions. Current requirements for these variants are different; helium ions, for instance, can be obtained only with difficulty, with currents of tens of m μA; helium positive ions beams, however, are readily obtained with currents of 10μA.

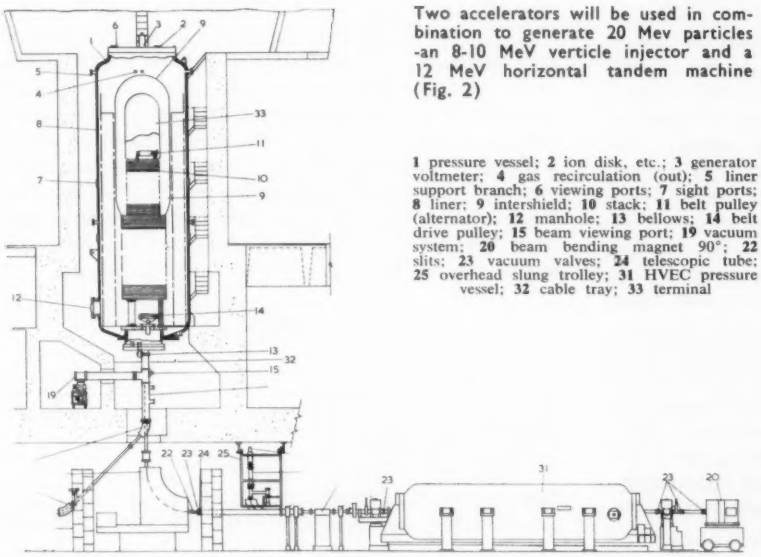
Because the demands on the ion source are considerable, the volume available to the ion source in the top terminal—9ft 6in × 5ft dia—is comparatively large. Another design complication, common to any single-ended generator, is the high potential required for the ion source—a potential cause of faults. By providing access to the top terminal by means of a small hoist inside the stack, minor faults in the ion source can be corrected without the necessity of removing the top pressure vessel lid and the terminal shells.

Whilst major difficulties are not envisaged for positive and negative operation—a simple reversal of the sign of the voltage on the spray charging device effects this—the stabilization of the negative running machine is a problem that is under investigation.

The new Nuclear Physics research laboratories, part of Oxford University's new Science Precinct, are to be equipped with an 8-10 MeV vertical Van de Graaff generator, designed by the National Institute for Research in Nuclear Science, coupled to a 12 MeV horizontal tandem generator to be purchased from the High Voltage Engineering Corporation of America.

A DSIR grant of £750,000 for the period up to December 1964 will cover the cost of the NIRNS machine and its housing, the construction and housing of the 12 MeV unit, and running costs up to July 31, 1962. Part of the running costs up to July 1967 may also be met. It is the largest single grant ever made by the DSIR.

The NIRNS is meeting the design and construction costs - £200,000 - of the 8-10 MeV unit. The University Grants Committee's grant of £75,000 for the period up to December 1964 is towards development costs.



Two accelerators will be used in combination to generate 20 Mev particles -an 8-10 MeV verticle injector and a 12 MeV horizontal tandem machine (Fig. 2)

1 pressure vessel; **2** ion disk, etc.; **3** generator voltmeter; **4** gas recirculation (out); **5** liner support branch; **6** viewing ports; **7** sight ports; **8** liner; **9** intershield; **10** stack; **11** belt pulley (alternator); **12** manhole; **13** bellows; **14** belt drive pulley; **15** beam viewing port; **19** vacuum system; **20** beam bending magnet 90°; **22** slits; **23** vacuum valves; **24** telescopic tube; **25** overhead slung trolley; **31** HVEC pressure vessel; **32** cable tray; **33** terminal

The theoretical analysis discussed last month is compared with the results of experiments

Burnout in liquid cooled reactors - 2

by J. G. COLLIER, B.Sc.(Eng.), A.M.I.Chem.E.,
Chemical Engineering Division, AERE, Harwell

HYDRODYNAMIC and heat transfer conditions in a vertical liquid cooled channel were discussed in detail in last month's article and a mechanism suggested for 'burnout' in the two phase forced convective region. This month a qualitative comparison is made of this suggested mechanism with experimental results. Some comments are also made on the experimental techniques used, and heat transfer when burnout heat flux has been exceeded is considered.

COMPARISON WITH EXPERIMENTAL RESULTS

The present empirical equations in general use (*2*) for the correlation and estimation of burnout heat flux in the quality region assume a monotonic relationship between burnout heat flux and quality and between burnout heat flux and mass velocity (Fig. 7*a*). These equations also indicate a maximum in the burnout heat flux versus system pressure relationship at about 1200 lbf/in²a. In the present section it will be shown that the relationship between burnout flux and quality, mass velocity and pressure are more complex than has hitherto been suggested.

Bell (*26*) was the first worker in the USA to suggest that the relationship between burnout heat flux and mass velocity was other than monotonic. He investigated the experimental data obtained by Westinghouse Atomic Power Division (WAPD) in rectangular channels at 2000 lbf/in²a and concluded that in the steam quality region the burnout heat flux *de*creased with increasing mass velocity (*G*). This effect was also suggested independently by Pexton (*27*). Since, however, in the subcooled region it was known that increasing mass velocity *in*creased the burnout heat flux, a relationship of the form shown in Fig. 7*b* was suggested. This, the writer believes, is the correct form of relationships between burnout heat flux and mass velocity and quality at pressures above 2000 lbf/in²a. This view is confirmed by the independent observations of Russian workers (*3, 29*). Bell was able, by invoking relationships of the form shown in Fig. 7*b*, to correlate the WAPD data without the inclusion of an L/D term which had been necessary in the original correlating equations (*2*). This appeared very encouraging since no easily understandable physical significance could be attached to the 'observed L/D effect'.

Using available Russian and American experimental observations, a qualitative picture of the relationships between burnout heat flux, mass velocity and quality can be built up for the pressures below 2000 lbf/in²a. The relevant observations may be summarised as follows:

1. Various Russian workers (*28, 29, 30*) have noted a maximum in the burnout heat flux versus quality relationship at constant mass velocity (G). This occurred at low values of mass velocity only. Above a limiting value of G which was apparently dependent on pressure, the burnout heat flux decreased monotonically with increasing quality. A decrease in pressure apparently increased this limiting value of G. The absolute values of the limiting mass velocity are uncertain and probably depend on the geometry of the test section. Reference (*29*) states that for a pressure of 380 lbf/in² the burnout heat flux initially increases with increasing quality up to values of G of $0{\cdot}9 \times 10^6$ lb/h ft². Reference (*28*) indicates that for this pressure a maximum in the burnout heat flux versus quality relationship was still being observed at a mass velocity of $2{\cdot}2 \times 10^6$ lb/h ft². However, these experiments were carried out on tubes of differing diameter.

2. The same Russian observations (*28, 29*) indicate that the position of the maximum in the burnout heat flux versus quality relationship and the value of the burnout heat flux at this maximum are also functions of the mass velocity. Below the limiting value mentioned above an increase in G causes the quality at which the maximum burnout heat flux occurs to decrease with a corresponding increase in the value of the burnout heat flux at the maximum. Again from reference (*28*) for one particular test section the results given in Table 1 may be quoted.

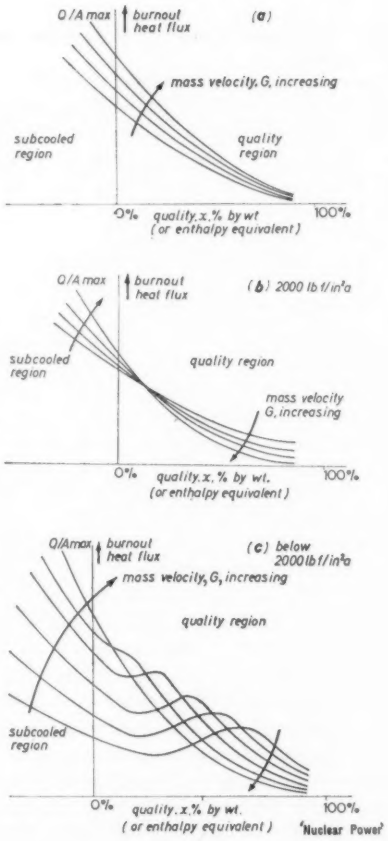
TABLE 1

PRESSURE		380 lbf/in²a	
Mass velocity	lb/h ft²	$0{\cdot}6 \times 10^6$	$2{\cdot}2 \times 10^6$
Steam quality at pt. of max. burnout flux ...	% by wt.	60%	25%
Max. value of burnout heat flux	Btu/h ft²	$0{\cdot}61 \times 10^6$	$1{\cdot}25 \times 10^6$

3. Measurements made at MIT by Reynolds (*31*) indicate that for constant steam quality and pressure (in the range 500 to 1500 lbf/in²a) an increase in mass velocity from 1 to 2 x 10^6 lb/h ft² causes a definite reduction in the burnout heat flux. It was also observed that at constant mass velocity and steam quality, the burnout heat flux decreased as the pressure was increased from 500 to 1500 lbf/in²a.

The foregoing observations may now be combined to give a picture of the relationships between burnout heat flux, steam quality, mass velocity and pressure below 2000 lbf/in²a. The proposed relationship is shown in Fig. 7*c*. It will be seen that in the subcooled and low quality regions, an increase in mass velocity causes an increase in burnout heat flux while the effect is reversed in the high quality region. At the lower mass velocities, maxima in the curves are indicated while at the highest mass velocities, a monotonic decrease of burnout heat flux with quality is shown. It is also suggested that a maximum occurs in the curve of burnout heat flux versus pressure (mass velocity and quality remaining constant) somewhere between atmospheric pressure and 500 lbf/in²a and that, at pressures above 500 lbf/in²a, the burnout heat flux decreases continuously, reaching zero at the critical pressure (c.f. reference (*32*) which refers to the subcooled region).

At this point it must be stated that there is no mention



Relationship between main variables; (a) after WAPD, (b) after [Bell, (c) as suggested by present work below 2000 lb/in²a (Fig. 7)

of maxima in the burnout heat flux versus quality relationships at low mass velocities in American literature. Indeed, only the data taken at the Argonne National Laboratory (*33*) at 600 and 1000 lbf/in²a give any evidence of such maxima when inspected. However, the occurrence in Russian literature is sufficiently common for the writer to consider that the fact that American workers have not observed the effect is due to differing experimental techniques. This idea is discussed in the next section.

The relationships shown in Fig 7*b* and 7*c* may be compared with that obtained from consideration of the stability of the liquid film on the heating surface (Fig. 6). It will be seen that the interpretation of experimental data suggested by Bell and in the present paper is in agreement with the ideas put forward in the section "A suggested mechanism for 'burnout' in the two phase-forced convective region" *Nuclear Power*, June, 1961, p.66.

The occurrence of an L/D effect remains in doubt. Bell's interpretation of the WAPD data indicated that the 'observed L/D effect' could be explained solely by the reversed effect of mass velocity in the higher quality regions. However, Russian measurements (*28*) made on test sections with L/D values of 11 and 50 with constant mass velocity show a very large effect; the values of burnout heat flux for the test section with an L/D value of 11 being larger by approximately a factor of two. This factor appears to be reduced somewhat by an increase in mass velocity or pressure. This observation cannot be explained by Bell's hypothesis and is so large as to have been easily detectable had such an effect occurred in the experimental WAPD data. Again it is suggested that differing experimental techniques could cause such a discrepancy between the Russian and American observations.

Comments on experimental techniques

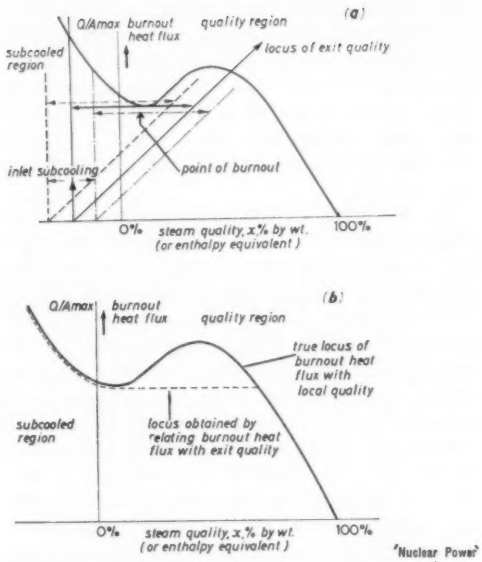
Measurement of the heat flux at the true point of burnout or failure of the heating surface would involve experimental workers in a very large amount of work and expense replacing the heated test sections after each test. In practise, in order to save the test section from damage so that it may be used in a number of tests, American workers have, in general, used some means of cutting off the heat flux immediately the heating surface temperature starts to rise from its value close to the saturation temperature. Two methods have been used to obtain an indication of the start of overheating. First, the use of thermocouples attached to the outside of the test section close to the exit of the heated length (*2*) and secondly, the use of the heated length as a resistance thermometer (*31*). In this method, the resistance of a small length of the heated tube near the exit is compared with the remainder of the tube by means of a Wheatstone bridge circuit. Any unbalance due to changes in resistance caused by changes in temperature will cause the bridge to be unbalanced, giving a signal which may be amplified to operate a trip. The assumption is inherent in these devices that burnout will always occur at the tube exit. The first American measurements to be carried out were in the subcooled region. Here, as previously discussed, burnout will take place at the exit of the heated length. Later American experiments were performd in the quality region using the same technique. Here again, provided the burnout

heat flux is a monotonic decreasing function of quality, the burnout point will be at the tube exit.

Let us examine what occurs when there is a maximum in the burnout heat flux versus quality relationship (Fig. 8*a*). Water is injected to the test section with an initial subcooling. As the heat flux to the section is increased so the exit quality is increased along the locus shown. At the condition indicated, where the horizontal line is tangential to the minimum in the curve, burnout will initially occur some way back from the tube exit. Varying the subcooling up or down slightly, as indicated by the dotted lines (all nominally tangential), will cause the point of burnout to move up or down the tube respectively leaving the burnout heat flux unaltered. This effect has been observed in experiments carried out by Averin and Kruzhilin (*34*) who point out that false interpretations may result from experimental measurements—if the burnout heat flux is always coupled with the quality at the tube exit (Fig. 8*b*). This may explain the fact that American workers have not observed a maximum in the burnout heat flux versus quality relationship. However, under the above conditions, burnout would have occurred in certain American experiments where there was little or no protection against damage of the tube. Hence, one would have expected physical burnouts to have occurred in a number of tests. It may be that the disruption of the liquid film at a point in the middle part of the tube will cause further disturbances down stream of the initial burnout point resulting in the trip device at the tube exit being initiated. It may also be that the disruption of the film occurs initially at a point in the middle part of the tube but the dry spot is carried along the tube to the exit where it initiates the trip. Evidence for this latter suggestion, which might also explain the so-called L/D effect, comes from experiments on 'dewetting' carried out by Hewitt (*35*). In these experiments with air and water in a perspex tube, a dry spot was caused to form in a liquid film carried up the inside of a tube by an air stream of about 100 ft/s. In a number of tests the dry spot itself moved up the tube for some distance with only a small diminution of area.

Details of the Russian workers' experimental equipment (*29*) are scanty and no details of the techniques used are published. However, it is believed that little in the way of protective devices are included on the test sections; removal of the heat flux is done by manual control when the operator sees incandescence of the tube or a large temperature rise indicated by thermocouples (*29*).

In previous experiments carried out in the USA, limitations have occurred due to the fact that the steam quality is not a totally independent variable but depends on the liquid mass velocity, inlet subcooling and the heat flux at burnout (Fig. 8*a*). Experiments now in progress at AERE, Harwell, and also in Italy (*18*) at CISE allow the steam quality at the entrance to the test section to be varied independently of the power to the test section. This allows an extension of the previous American experimental results. Measurements of the form of the burnout heat flux versus quality relationship may now be made in the region of the maxima by putting burnout protection on both the inlet and exit parts of the heated length. It is suggested that this technique of injection of steam-water mixtures of controlled quality to the test section was probably also used in the quoted Russian experiments (*28, 29, 30*)



(a) Condition where burnout does not occur at the test section exit; (b) true and 'false' burnout heat flux versus quality relationships (Fig. 8)

enabling the Russian workers to investigate the region of the maxima. Evidence for this comes from the small amount of detail given in reference (*29*).

Heat transfer under conditions where burnout heat flux has been exceeded

The mechanism of heat transfer under conditions where the burnout heat flux has been exceeded is dependent on whether the initial condition before burnout was the process of 'boiling' (i.e., the subcooled or low quality regions) or the process of 'evaporation' (i.e., the higher quality regions).

Film boiling in the subcooled and low quality regions. When the burnout heat flux has been exceeded in the subcooled or low quality regions the process of film boiling is initiated. As was briefly mentioned in the section 'The subcooled boiling region', NUCLEAR POWER, June, 1961, p.63, an insulating vapour film covers the heating surface through which the heat must pass. The heat transfer coefficient is orders of magnitude lower than in the previous condition before burnout due mainly to the lower thermal conductivity of steam. Typical values for the heat transfer coefficients in this region are in the range 30–300 Btu/h ft² °F which coupled with the high heat flux required to initiate film boiling in the subcooled or low quality regions $>1 \times 10^5$ Btu/h ft²) results in extremely high temperature differences (~3000°F). Failure of the heating surface usually results. The affect of increasing pressure would be expected to increase the 'film boiling' coefficient due to the increase of the thermal conductivity of the vapour. The liquid stream velocity would also be expected to have an effect (*36*). A higher liquid velocity would cause increased shear at the vapour film-liquid interface, leading to a thinner vapour film and hence an increased heat transfer coefficient. Theoretical treatments of the film boiling process are available (*37, 38*) but there appears to be a complete lack of experimental data for the film boiling of water in vertical tubes.

Heat transfer in the liquid deficient region. Until very

recently, hardly any knowledge of the heat transfer processes in the region known as the 'liquid deficient region' (Section G, Fig. 1) was available. However, Parker and Grosh (*39*) have recently published a study of this particular condition which presents some interesting findings.

There appear to be two distinct mechanisms of heat transfer which can occur, depending on the value of the surface temperature. If the surface temperature is below the value at which the spheroidal state is initiated (the Leidenfrost point), droplets from the vapour core are able to wet the heating surface when striking the tube wall. They are totally evaporated and deposit any solids dissolved in the liquid on the heating surface (*40*). Parker and Grosh state that heat transfer coefficients in this region are between three and six times the value expected for dry steam flowing under the same conditions. At atmospheric pressure the Leidenfrost point appears to occur some 80–100°F above the saturation temperature. For heater surface temperatures above this value the droplets can no longer wet the tube wall and heat transfer coefficients noted by Parker and Grosh and at AERE, Harwell (*41*) are almost identical to those for dry steam even though a considerable amount of liquid remains entrained in the vapour stream. Under these conditions it appears that a superheated boundary layer of steam is formed near the surface and that the assumption of equilibrium between the phases is no longer correct. The entrained droplets evaporate relatively slowly and the outlet steam may be considerably superheated before the last droplets disappear. Indeed, Parker and Grosh were able to correlate their measured heat transfer coefficients with those for dry steam by assuming that *no* evaporation of droplets occurred in the channel and that all the heat transferred was taken up in increasing the steam temperature.

Increases in pressure tend to reduce the difference in temperature between the saturation value and the Leidenfrost point and in most practical cases where the burnout heat flux has been exceeded, the temperature of the surface will jump to a value above the Leidenfrost point. Coefficients to dry steam (*42*) depend on the temperature, pressure and flow of the steam together with channel geometry but values up to 2000 Btu/h ft² °F are common at high pressure. This coupled with the reduced burnout heat flux values in the higher quality regions ($\sim 0{\cdot}5 \times 10^6$ Btu/h ft²), means that the surface temperature beyond the burnout point in Section G (Fig. 1) may be only about 250°F above the saturation temperature. This is an important fact when considering the safety margin which must be placed on the design operating conditions in a reactor channel. Obviously, if the consequences of a burnout occurring are less serious at high qualities then the design operating conditions may be allowed to approach the burnout point more closely.

CONCLUSIONS

1. The hydrodynamic conditions existing in a vertical tube in which vaporization is occuring are of the greatest importance in studying the heat transfer characteristics of the system. Changes in the two-phase flow pattern have been shown to change completely the mechanism of heat transfer. The mechanism of burnout in the various regions considered (subcooled, low quality and high quality) has also been shown to be governed by the hydrodynamic conditions existing in the channel at the particular point considered.

2. Burnout in the subcooled and low quality regions is believed to be caused by the interaction of unstable bubble columns (*4*). In the higher quality regions the disruption of the liquid film on the heating surface is the suggested mechanism of burnout. This is thought to be due to surface tension differences in the rippling liquid film causing instability.

3. The relationship between burnout heat flux and quality, mass velocity, and pressure may not be as simple as has previously been suggested. Throughout the pressure range it appears that the effect of increasing mass velocity is to cause an increase in the burnout heat flux in the subcooled and low quality regions while causing a decreased burnout heat flux in the higher quality regions. While the burnout heat flux is a monotonic decreasing function of steam quality at high pressure (>2000 lbf/in²a), at lower pressures and particularly at low values of mass velocity, the burnout heat flux appears to pass through a maximum in the quality region. The lower the mass velocity the higher the steam quality at the point of maximum burnout heat flux and the lower the value of this maximum burnout heat flux.

4. Heat transfer beyond the burnout point is dependent on the initial conditions before burnout. In the subcooled or low quality regions the process of film boiling is initiated with the probable resulting destruction of the heater surface. At higher qualities the heat transfer mechanism is dependent on the surface temperature: above the Leidenfrost point, coefficients are almost exactly similar to dry steam coefficients under the same conditions. Under conditions of high quality and pressure the coefficient may be high enough to prevent substantial damage to an element after nominal burnout.

ACKNOWLEDGMENTS

In a paper of this nature many of the ideas which are presented are the outcome of discussions with a large number of people. In particular, the writer would like to acknowledge the frequent and helpful discussions with his colleagues, Mr P. M. C. Lacey and Dr G. F. Hewitt, and also with Mr R. W. Bowring, Mr A. Pexton and Mr H. A. Roberts. The writer would also like to acknowledge the helpful discussions and exchange of ideas with the members of the Italian team working at CISE, Milan.

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PUMPS IN ATOMIC ENERGY

A 'Nuclear Power' survey

DETAILS LISTED in this survey were obtained from information supplied to *Nuclear Power* by the manufacturers. Operating characteristics of the pumps are given as well as the type and purpose according to the accompanying key. This survey has been made as comprehensive as possible but should not be regarded as complete as many manufacturers do not know the final destination of their products.

Besides the large number of conventional pumps used in nuclear power installations, e.g. boiler feed pumps, etc., many interesting special purpose pumps have been developed. These include the big gas blowers able to circulate large quantities of carbon dioxide at high temperatures and pressures, pumps for liquid metals, and pumps used in chemical plants able to withstand highly corrosive and active liquids. These special pumps are characterized by their high standards of leak tightness and the need for maintenance-free running.

KEY

Pumps (by type)

Rotodynamic
1 Axial flow
2 Canned rotor
3 Centrifugal (horizontal)
4 Centrifugal (vertical)
5 Magnetic coupling
6 Mixed flow
7 Multistage
8 Self-priming
9 Submerged motor
10 Water ring
11 Gas bearing motor

Positive Displacement
12 Diaphragm
13 Gear or lobe
14 Metering
15 Reciprocating (sing. cyl.)
16 Reciprocating (multi. cyl.)
17 Screw or helix
18 Vane
19 Variable delivery

Electromagnetic
20 ac conduction
21 dc conduction
22 ac induction, flat linear
23 ac induction, annual linear
24 ac induction, rotating magnet
25 ac induction, spiral

Borehole
26 Reciprocating
27 Shaft-driven centrifugal
28 Submersible centrifugal

Gas circulators
29 Centrifugal
30 Axial flow

Pumps (by purpose)

a Boiler, circulator
b Boiler, feed
c Cold water
d Condensate extraction
e Filter
f Bulk fuel transfer
g Sea water
h Steam
i Heavy water
j Liquid metal, electromagnetic
k Liquid metal, mechanical
l Radioactive Effluent
m Acid
n Alkalis
o Organic fluids
p Oils
q powders
r Semi-solids
s Sludge
t Slurry
u Vacuum, high, ion getter
v Vacuum, high, mercury diffusion
w Vacuum, high, oil diffusion
x Vacuum, rotary
y Gases
z Hydraulic test

TYPE & PURPOSE		CAPACITIES	PRESSURE OR HEAD	MATERIALS OF CONSTRUCTION	TEMP.	METHODS OF DRIVE	WHERE SUPPLIED	FUNCTION & NOTES
Charles Austen Pumps Ltd								
12	y	0-60 l/min	60 lbf/in²	ss	Ambient	Electric motor	UKAEA	Non-contaminating, leak-proof, continuous running
3, 4	c, g	0-300 gal/h	30 ft	Bronze or bakelite	Ambient	Electric motor	UKAEA	Variable output
AEI Instrumentation Division, Scientific Apparatus and X-ray Department								
18	x	0·4-33 l/s		Mild steel	Normal	Belt and direct drive	All UKAEA establishments	General vacuum pumping
	w	40-5000 l/s	10^{-4} and below	Mild steel, ss	Normal		All UKAEA establishments	Vacuum systems for general laboratory use, and special systems such as Zeta, proton linear accelerators, Van de Graaff Generators
W. H. Allen Sons & Co. Ltd								
4	c	50,000 gal/min	67 ft	C.I. casing. Impeller Staybrite steel. Renewable Staybrite sleeves on high tensile mild steel shaft	85°F	1225 hp electric motor	Merz & McLellan Chapelcross	Cooling water circulation for the turbo-alternator condensers through the cooling towers
Appleton and Howard Ltd								
4	m	20 gal/min	Up to 160 ft	Monel	20°C	Electric motor	UKAEA	Pumping HF, safety
4		30 gal/min	30 ft	Pure nickel		Electric motor	UKAEA	Beryllium chloride, high temperature
Barflo Ltd								
		3 gal/min		Plastic		Hand operated		For handling small amounts of corrosive fluids
Sir W. H. Bailey & Co. Ltd								
16		110 gal/h	400 lbf/in²	C.I. body stainless steel rams, stainless steel valves and seats	Normal	Motor through gears	John Thompson Kennicott	Boiler dosing with tri-sodium phosphate solution. Type 15 also produced
James Beresford & Son Ltd								
2, 9, 28	c		1200 ft (max)	Bronze and ss	Cold water	Electric motor		
7		960 gal/h	360 ft head	Bronze		Electric motor	Harwell	Demineralized water
8	m	900 gal/h	70 ft	Bronze & ss		Electric motor	Windscale	
4	c	3600 gal/h		Iron	Cold water	Electric motor	Windscale	Sump Drainage
4	m	2500 gal/h		Bronze & ss		Electric motor	Windscale	Citric acid
8	c	5600 gal/h		Alloy	Cold water	Petrol engine	Winfrith	
3	c	10,300 gal/h		Bronze & ss		Electric motor	Risley	

TYPE & PURPOSE		CAPACITIES	PRESSURE OR HEAD	MATERIALS OF CONSTRUCTION	TEMP.	METHODS OF DRIVE	WHERE SUPPLIED	FUNCTION & NOTES
Henry Berry & Co. Ltd								
16	c	6 gal/min	2240 lbf/in²	Various	Normal	13 hp electric motor	UKAEA Windscale	Process
Berry Hill (Engineers) Ltd								
13	f	20 gal/min	120 ft	C.I.	50°C	Direct coupled to electric motor	UKAEA Springfield	Oil transfer. Incorporated in oil transport truck
13	f	10 gal/min	75 ft	C.I.	50°C	Direct coupled to electric motor	UKAEA Springfield	Oil transfer. Incorporated in oil transport truck
3	c	500 gal/min	21·5 ft	C.I.	17°C	Direct coupled to electric motor	UKAEA Risley	
17	t	10 gal/min	50 ft	C.I.	17°C	Direct coupled to electric motor	UKAEA Risley	Abrasive slurry collection. Mounted with tank on mobile trolley
3	c	600 gal/min	60 ft	C.I.	17°C	Direct coupled to electric motor	UKAEA Risley	
Boughton Pumps Ltd								
12			Up to 25 cm Hg	Aluminium	Up to 70°C	Electric vibrator	UKAEA Harwell, Dounreay	None require maintenance, oiling, etc.; fluids pumps—self-priming; all sealed for gases, etc.; miniature size—2½ in dia. × 2½ in long, cylindrical; light weight—20 ozs; adaptability as component; custom-built to produce required performance
			Up to 3½ lbf/in²	Aluminium alloys			Honeywell Controls Motherwell	
		0·3 l/min at 6 ft head		Polyurethane			Ferranti Edinburgh Decca Radar London	
British Central Electrical Co. Ltd								
		2000 gal/h	25 ft	ss or Al		Electric motor		General purpose portable barrel type
David Brown Industries Ltd								
13	p			C.I., steel rotors				Low pressure, high delivery
Clarke, Chapman & Co. Ltd & E. N. Mackley & Co. (Branch of Clarke, Chapman & Co. Ltd)								
16	p	200 gal/h	2000 lbf/in²	Forged steel pump block, steel rams	Normal	Electric motor through Gears	C. A. Parsons for UKAEA Chapelcross	Turbine jacking
27	l	30 gal/min	50 ft	ss		Electric motor	UKAEA Windscale	
27	l	20 gal/min	26 ft	ss		Electric motor	UKAEA Windscale	
C.T. (London) Ltd, *agents for Société Corblin*								
			30,000 lbf/in²	ss, monel, plastic, etc.				Circulating D_2O, corrosive liquids, etc Glandless, diaphragm type
Davidson & Co. Ltd								
29	y				High	Electric motor	GEC, Zenith Reactor at UKAEA Winfrith	Nitrogen coolant circulation, air lubricated shaft seal
29	y		Up to 300 lbf/in² circuit pressure	Alloy steel	Up to 300°F	Variable speed electric motor	International Combustion (N.A.) Ltd, nuclear test rig	Air /CO_2 circulator, Crane double supercooled seal
29	y	50 ft³/min	10 in w.g.	Steel	140°F	Electric motor	International Combustion (N.A.) Ltd, AGR Windscale	Air purging
29	y			Steel		Electric motor	International Combustion (N.A.) Ltd, AGR Windscale	Carousel cooling CO_2 fans, Crane double mechanical seal
29	y			Steel		Electric motor	International Combustion (N.A.) Ltd, AGR Windscale	Mortuary CO_2 circulators, Crane double mechanical seal
29	y	1570 ft³/in	4 lbf/in²	Alloy steel	Atmospheric	Electric motor	Fairey Engg. Ltd	Nuclear test rig cooling air blower
29	y						Fairey Engg. Ltd Hector reactor at UKAEA Winfrith	CO_2 coolant circulation
Doulton Industrial Porcelains Ltd								
12	m	300 gal/h	15 ft	Stoneware	Ambient	Hand operated	AERE Harwell AWRE Aldermaston	Hypalon valves and diaphragms
Drysdale & Co. Ltd								
3	g	88,580 gal/min	46 ft	C.I. casing ss impeller	Normal	Electric motor	TNPG Dungeness	Condenser cooling
3	g	97,250 gal/min	31 ft	C.I. casing 3% N.C.C.I. impeller	Normal	Electric motor	APC Trawsfynydd	Condenser cooling
3	g	113,000 gal/min	40·5 ft	C.I. casing ss impeller	Normal	Electric motor	English Electric Co. Ltd Sizewell	Condenser cooling
ECD Ltd								
12	i	5-10 ft³/min	10 lbf/in²	Aluminium head with Neoprene valves & diaphragm	Ambient	Electric motor	Head Wrightson Processes Harwell reactor	Leak-tight glandless metering pump
12	n	0-10 gal/h	134 ft	Diaphragm nat. rubber, head P.V.C. block, jumpers P.V.C.	Ambient	Electric motor	UKAEA Warmwell, Dorset	Glandless metering pump
12	c	0-20 gal/h	100 ft	Diaphragm nat. rubber, head F.M.B. ss, valves F.M.B. ss	Ambient	Electric motor	G. N. Haden Chorley Lancs.	Glandless metering pump
12	m		60 lbf/in²g	Diaphragm nat. rubber, head F.M.B. ss, valves F.M.B. ss	Ambient	Electric motor	UKAEA Dounreay	Glandless metering pump
12	m	0-35 gal/h	40 lbf/in²g	Diaphragm p.t.f.e. head F.M.B. ss	30°C	Electric motor	UKAEA Dounreay	Glandless metering pump arranged for remote control
12	m	0-17·5 gal/h	12 ft	Diaphragm p.t.f.e., head F.M.B. ss	Ambient	Electric motor	UKAEA Caithness	Glandless metering pump arranged for remote control
12	m & n	0-15 gal/h	20 lbf/in²g	Valves F.M.B. ss, diaphragm nat. rubber, head F.M.B. ss, C.L.V.	Ambient	Electric motor	Honeywell Control Winfrith	Glandless metering pump, arranged for pneumatic stroke control
12	m & n	0-4·5 gal/h ...	20 lbf/in²g	Diaphragm nat. rubber head P.20 ss, valves P.20 ss, C.L.V.	Ambient	Electric motor	Honeywell Control Winfrith	Glandless metering pump, arranged for pneumatic stroke control

TYPE & PURPOSE		CAPACITIES	PRESSURE OR HEAD	MATERIALS OF CONSTRUCTION	TEMP.	METHODS OF DRIVE	WHERE SUPPLIED	FUNCTION & NOTES
English Electric Co. Ltd								
22	j	400 gal/min	30 lbf/in²	ss steel tube, electrical steel core plates, copper windings	250°C	Electro-magnetic	UKAEA Dounreay fast reactor. Also at Windscale and Capenhurst	Sodium pumping
Firth Cleveland Ltd								
3, 4, 7, 8, 10, 15, 27, 28	a, b, c, f, g, l, m, n, o, p, t							
Fleischmann (London) Ltd (*All these pumps were manufactured by W. C. Heraeus GmbH, Hanau, Western Germany*)								
13		940 ft³/min	10⁻³ Torr	Mild steel	Ambient	Direct	UKAEA Dounreay	Evacuating vacuum arc-melting furnace (Rootes pump) 4 other units for similar purposes supplied for nuclear energy applications, but present situations not disclosed
13		235 ft³/min	10⁻³ Torr	Mild steel	Ambient	Direct	UKAEA Capenhurst	2 other units for similar purposes, but present situations not disclosed
	x	53 ft³/min	0·0001 Torr	Mild steel	Ambient	Direct		6 units supplied for N.E. work, but present situations not disclosed; rotating plunger type
	x	79 ft³/min	0·005 Torr	Mild steel	Ambient	Direct	AWRE Aldermaston	
	w	2000 l/s	10⁻⁶ Torr	Mild steel & Al	Ambient			Evacuating vacuum sintering furnaces. Present whereabouts not disclosed
	w	8000 l/s	10⁻⁸ Torr	Mild steel & Al	Ambient			Leak testing application. Present whereabouts not disclosed
	u	25 l/s	1×10^{-10} Torr	Mild steel				General research in connection with N.E. applications
General Engineering Co. (Radcliffe) Ltd								
	x	27-310 ft³/min	10⁻³ mm Hg	Steel		Electric	UKAEA	Positive rotary displacement piston type
	x	130-230 ft³/min	2×10^{-6} mm Hg	Steel		Electric	UKAEA Nimrod	Rootes type
Gilbert, Gilkes & Gordon Ltd								
8	c, g						Crossley Bros Ltd Dounreay, Chapelcross, Windscale	Cooling water duties on standby diesels
Girdlestone Pumps Ltd								
12	l, i	0-600 gal/h	80 lbf/in²	Ebonite lined	Ambient	Electric motor	AEE, Trombay, India	
8	l	0-1500 gal/h	25 lbf/in²	ss	Ambient	Electric motor	UKAEA	Effluent treatment
3	d	10-36,000 gal/h	50 lbf/in²	Gunmetal, C.I.	0-100°C	Electric motor		
Greenwood & Batley Ltd								
16	c	4000 in³/min	700 lbf/in²	Mild steel, ss, phos. bronze & C.I.	Ambient, 60°F	Direct motor	UKAEA Pond No. 2 Windscale Works	Supply of water to H.P. accumulator services operating underwater fuel storage, handling coffin hoist & unloading equipment
16	a	300 gal/min	4000 lbf/in²	Mild steel, ss, p.t.f.e. glands	180°F	Direct motor	Foster Wheeler Ltd Barrow	Secondary heat transfer circuit test loop
Hamworthy Engineering Ltd								
3	c	400 gal/min	40 ft	C.I.	Ambient	Flex. coupling	UKAEA Harwell	Std water pump
3	c	35 gal/min	33 ft	C.I., ss impeller	Ambient	Flex. coupling	UKAEA Harwell	Flexibox seal, self priming unit
13	p	335 gal/min	10 lbf/in²	C.I.	Ambient	Flex. coupling	AWRE Foulness	Transfer, Std pump
3	c	42 gal/min	53 ft	C.I.	Ambient	Flex. coupling	UKAEA Harwell	Circulating. Flexibox seal, self priming unit
3	c	133 gal/min	13 ft	Gunmetal	104°F	Flex. coupling	UKAEA Harwell	Transfer. Mechanical seals, gunmetal fittings
3	b	20 gal/min	87 lbf/in²	C.I.	Ambient	Flex. coupling	AERE Winfrith	Feed. Std pump
3	c	110 gal/min	120 ft	Gunmetal	Ambient	Flex. coupling	UKAEA Harwell	Flexibox seal, non-self-priming
3		400 gal/min	30 ft	C.I. casing, gunmetal impeller, ss spindle		Electric motor	UKAEA Dounreay	Automatic self-priming
3		500 gal/h	45 ft + 5 ft suction lift	Gunmetal casing, alloy steel rotors and spindles	65°F	Electric motor	UKAEA Dounreay	
Hayward Tyler & Co. Ltd								
2, 3, 4, 6, 7, 9, 16, 28	a, c, f, g, h, i, l, m, n, o, p, t		Up to 5000 lbf/in²				All UKAEA research reactors & experiments. Civil power stations. Extensively supplied to atomic energy establishments in USA, Canada, Norway, Australia, Denmark, Germany, France, Sweden, Japan, India, Italy	Glandless motor pumps either of wet stator or dry stator canned construction used on test loops, heavy water primary circulation, heat exchanger circuits, etc
The Harland Engineering Co. Ltd								
3, 4, 6, 7, 8, 9, 27, 28	a, b, c, f, g, o, p, s, t							
Holden & Brooke Ltd								
4	l			Ferrous	Normal	Direct coupled electric motor	Simon-Carves, Hunterston	Pumping effluent from collecting sump
4	c			C.I., gunmetal	Normal	Direct coupled electric motor	Windscale	Surface water to main drain
4	c			C.I.	Normal	Direct coupled electric motor	Calder Hall	Drainage pumping from sumps
3	b			C.I., cast steel, gunmetal	200°F	Direct coupled electric motor	Bradwell	Boiler feed
3	a			C.I., gunmetal	180°F	Direct coupled electric motor	Aldermaston	Closed circuit pumping
3	b			C.I., cast steel, gunmetal	200°F	Direct coupled electric motor	Aldermaston	Boiler feed
3	c			C.I., gunmetal	Normal	Direct coupled electric motor	Harwell	Cold water circulation

TYPE & PURPOSE		CAPACITIES	PRESSURE OR HEAD	MATERIALS OF CONSTRUCTION	TEMP.	METHODS OF DRIVE	WHERE SUPPLIED	FUNCTION & NOTES
B. A. Holland Engineering Co. Ltd								
18	y	100 ft³/min	40 lbf/in²	C.I. & steel	70°F	Direct coupled	AEE Winfrith	Compressor
18	x	200 lb/h	Vac. 2 lbf/in²a	C.I. & steel	23°F	Direct coupled	British National Hydrogen Bubble Chamber, Harwell	Vac. pump
18	x	Displacement 1685 ft³/min	28 in vac.	C.I. & steel	70°F	Direct coupled	CEGB, Berkeley	Vac. pump
W. C. Holmes & Co. Ltd								
13	y	52,800 ft³/h	5 lbf/in²			Motor & V rope	Babcock & Wilcox	
13	y	15,900 ft³/h	15 lbf/in²			Motor & V rope	Babcock & Wilcox	
13	y	21,120 ft³/h	15 lbf/in²			Motor	Babcock & Wilcox	
13	y	27,000 ft³/h	8 lbf/in²				UKAEA Dounreay	
Hydraulics & Pneumatics Ltd								
19	p	1·5 gal/min	2500 lbf/in²		Ambient	Direct electric	UKAEA Aldermaston	Standard production model type AVD 29
Integral Ltd								
180	p	5 gal/min	2000 lbf/in²			Electric motor	Harwell	Four pumps used to supply fluid to Integral Type 197 Motors. One driving each wheel of heavy duty Transporter bogie
300	c	5 gal/min	3000 lbf/in²			Electric motor	Foster Wheeler Ltd Naval Vessel	Make-up pump used for cooling purposes
International Combustion (Nuclear Applications) Ltd								
	a	313,400 lb/h	25 lbf/in²	Low carbon steel casings with ss internals	500°F	Constant Speed	UKAEA AGR Windscale	Electromersible type for assisted circulation of boiler evaporator circuit
	a	621,700 lb/h	40 lbf/in²		426°F	Constant Speed	CEGB, Trawsfynydd	Electromersible type for assisted circulation of boiler evaporator circuit
		897,300 lb/h	40 lbf/in²		544°F	Constant Speed	CEGB, Trawsfynydd	Electromersible type for assisted circulation of boiler evaporator circuit
Kontak Manufacturing Co. Ltd								
12, 14, 19	c, i, k, m, n, o, t,	0-7 l/min mainly in the range 0-1 l/min	Up to 2000 lbf/in²	ss & p.t.f.e., ss, Monel & p.t.f.e.	Ambient	Reciprocating oil actuating pump electrically driven	UKAEA, CEA Marcoule, AAEC, AEI Merlin	For metering active liquids, all metering heads are glandless
Lee, Howl & Co. Ltd								
3, 4, 7		75-1150 gal/min	Up to 288 ft	C.I. casing, impellers C.I. gunmetal, cast steel, drawn phosphor bronze sleeves	Up to 200°F	Direct through flexible coupling	Hunterston, Hinkley Point, Bradwell	For demineralized water, clean water, drainage water, radioactive water
Mather & Platt Ltd								
1, 2, 3, 7, 27	a, b, c, d, g, p	Up to 57,500 gal/min	Up to 2140 ft	C.I., ss, mild steel phosphor bronze	Up to 390°F	Motor or turbine	Aldermaston, Berkeley, Bradwell, Calder Hall, Capenhurst, Chapelcross, Dounreay, Hinkley Point, Sizewell, Springfield, Trawsfynydd, Windscale	Circulating water, main drainage, hydrogen cooling, lubricating oil, fire pump, etc
Merrill Pumps Ltd								
12	c	12 gal/min	50 ft	C.I. and rubber	Ambient	Electric motor	UKAEA Windscale	Sump emptying
12	l	50 gal/min	200 ft	Hypalon and PVC	Ambient	Electric motor	Head Wrightson Bradwell	Transfer pumping on effluent treatment plant
L. A. Mitchell Ltd								
2, 3, 4, 12, 14	i, m, n, o, p							Pumps recently installed in association with Chempump (Great Britain) Ltd
Mono Pumps Ltd								
17	b, c, e, f, g, l, n, o, p, q, r, s, t							
D. Napier & Son Ltd								
29	y	750 ft³/min	1·84 lbf/in²	ss	50°C	Electric	Nydquist & Holm Atomenergei Sweden Reactor R3/ADAM	Fuelling m/c cooling, gas bearing, cammed Working parts removable as cartridge
29	y	(a) 7 lb/s (b) 0·9 lb/s	(a) 255·8 lbf/in²a (b) 15 lbf/in²a	Carbon steel	(a) 200°C (b) 100°C	Electric	Fairy Engineering/ CEGB Trawsfynydd (Under construction)	Fuelling m/c cooling, gas bearing, cammed Working parts removable as cartridge
N.G.N. Electrical Ltd								
18	x	1-12 ft³/min	10^{-3} to 10^{-6} mm Hg	Mild steel		Electric motor	UKAEA Harwell, Aldermaston, Winfrith & Springfield	General purpose vac. pumps
	w	25-125 l/s	5×10^{-6} mm Hg	Mild steel & Al			UKAEA Harwell, Aldermaston, Winfrith & Springfield	General purpose
Neumo Ltd								
8, 19, 26	a, b, c, e, d, e, f, g, h, l, m, n, o, p, s, t, z	0-1200 gal/h	0-750 lbf/in²	Steel, brass, ss, fluon	0-200°F	Air		

TYPE & PURPOSE		CAPACITIES	PRESSURE OR HEAD	MATERIALS OF CONSTRUCTION	TEMP.	METHODS OF DRIVE	WHERE SUPPLIED	FUNCTION & NOTES
Northey Rotary Compressors Ltd								
13	x, y	Up to 350 ft³/min displ	Up to 70 lbf/in²g or vacua to within 0·5 mm Hg abs	Standard, ss, Mechanite, mild steel, light alloy		Direct or belt	Aldermaston, Dounreay, Harwell, Capenhurst, Springfield, Winfrith, Bradwell, Denmark, Germany, India, Switzerland	For compressing air, CO_2, inert gases and vacuum pumping
13	y	29,000 lb/h	360 lbf/in²g inlet, 405 lbf/in²g outlet	SG iron		Belt	Harwell	Air pump
Palatine (Surbiton) Ltd								
22	j	10-18 gal/min	18 lbf/in²	Contact parts in 18/8/1 ss	400°C (600°C special)		UKAEA R & D Labs. Also Dounreay, Harwell, Rolls-Royce, ICI, APV	Used for pumping liquid sodium in loops manufactured by Palatine and operated by the UKAEA for research into corrosion of reactor materials
2		4 gal/min	22 lbf/in²	18/8/1 ss		½ hp canned electric motor	UKAEA Industrial Group & Harwell	For radioactive and toxic fluids, glandless construction, entirely seal welded, leakage completely eliminated
G. C. Pillinger & Co. Ltd								
3	c	80 gal/min	35 lbf/in²	C.I. & gunmetal	Ambient	Vee belt drive	CEGB Laboratories Leatherhead	Pressurizing cold water supply to laboratory
3	c	45 gal/min	60 lbf/in²	C.I. & gunmetal	Ambient	Direct coupled	AWRE Aldermaston	Pressurized water supply fire hose
		33 gal/min	60 lbf/in²	C.I. & gunmetal	Ambient	Direct coupled	Trawsfynydd	Pressurizing mains water supplies for general purposes
3	c	200 gal/min	60 lbf/in²	C.I. & gunmetal	Ambient	Direct coupled	Bradwell	Pressurizing mains water supplies for general purposes
3	c	50 gal/min	160 ft	C.I. & gunmetal	Ambient	Direct coupled	Dungeness	Pressurizing mains water supplies for general purposes
Plannair Ltd								
29	y	5000 lb/h	9 lbf/in²	ss	100°C	Direct drive from 400 cycle motor with conventional prepacked grease bearing arrangement	UKAEA through Vickers-Armstrong Experimental Irradiation rig in DMTR in connexion with AGR	Circulation of CO_2 at 285 lbf/in²a for in-pile experimental rig. Experiment details in I.Mech.E. paper 'Design of Irradiation Experiments'. A variable frequency supply permits adjustment of speed & flow. Circulator & motor are completely contained within vertical 6¼ in bore pressure tube (zero leakage) A secondary impeller circulating CO_2 over a water cooling coil maintains even operating temperatures for motor and bearings
30	y	750 ft³/min	2·4 in w.g.	Mechanite	Normal	Direct drive from integral 50 cycle motor	UKAEA through Vickers-Armstrong Experimental irradiation rig in Calder reactor	Circulation of air over heat exchanger; used in conjunction with CO_2 circuit to maintain correct experimental temperatures
Q.V.F. Ltd								
3	m	55 gal/min (max)	25 ft (max)	Borosilicate glass, fluon	Up to 150°C	Direct electric		All glass pump for corrosive materials, mechanical seal
		110 gal/min (max)	50 ft (max)					
Saunders Valve Co. Ltd (Safran Pump Division)								
3		20 gal/min	160 ft	FCB ss	40°C	Monobloc electric	UKAEA Didcot	Demineralized water
3				C.I. casing, gunmetal impeller		Monobloc electric	UKAEA Caithness, Winfrith	
3		1 gal/min	15 ft	18/8/1 ss		Monobloc electric	UKAEA Risley	Demineralized water
3		72 gal/min	75 ft	FMB ss	158°F	Monobloc electric	UKAEA Risley	
3	c	20 gal/min	100 ft	C.I. casing, gunmetal impeller		Monobloc electric	UKAEA Risley	
2	a	8 gal/min	4 ft	C.I. casing, gunmetal impeller	180°F	Monobloc electric	UKAEA Capenhurst	
3	c	7·2 gal/min	80 ft	All bronze	180°F	Monobloc electric	UKAEA Aldermaston	
3		20 gal/min	160 ft	All bronze	40°C	Monobloc electric	UKAEA Oxford	Demineralized water
Stothert & Pitt Ltd								
3, 4, 8, 13, 17, 19	f, g, m, n, p, s, x	400 gal/h	50 lbf/in²	Ferrous		Motor	Harwell	
Sulzer Bros. (London) Ltd								
1, 2, 3, 4, 6, 7, 9, 10, 27, 28, 29, 30	a, b, c, d, e, f, g, l, m, n, p, s, t, y, z						Chapelcross, Dounreay, Windscale and Winfrith	
Sumo Pumps Ltd								
2, 9, 7	g	400 gal/min	115 ft	Bronze, ss	Ambient	Electric, direct coupled	Bradwell	To dewater cooling water outfall culvert for inspection
2, 9	g	250 gal/min	50 ft	C.I., bronze fitted, ss shaft	Ambient	Electric, direct coupled	Bradwell	Drainage
Vacuum Research (Cambridge) Ltd								
10	x	100 ft³/min	20 mm Hg abs	ss, bronze	Ambient	Electric	AEI	Handling furnace degassing for melting plant
13	x	1500 ft³/min		Mild steel, bronze				Used in conjunction with the above
15	x	15 ft/min	0·001 mm Hg				AWRE	Annealing furnace for radioactive materials
29	y							For cooling above
15, 16	v, x						SERL	
15	x, v						Cavendish Lab.	Nuclear material investigation
								Note: all the above pumps were not manufactured by Vacuum Research but were supplied in equipment purchased by nuclear organisations

TYPE & PURPOSE		CAPACITIES	PRESSURE OR HEAD	MATERIALS OF CONSTRUCTION	TEMP.	METHODS OF DRIVE	WHERE SUPPLIED	FUNCTION & NOTES
Vickers-Armstrongs (Engineers) Ltd								
19	p	Various	1000 lbf/in²	Various			Babcock & Wilcox Ltd GEC etc. Windscale, Chapelcross, Hunterston	Variable speed drives for skip handling equipment, carousels, etc
The Watson-Marlow Air Pump Company								
14, 19	d, g, i, k, l, m, n, o, p, q, s, t, y							
G. & J. Weir Ltd								
		Up to 1,000,000 lb/h	Up to 880 lbf/in²g		Up to 260°F		Hunterston, Berkeley, Hinkley Point	Boiler feed pumps
Whittaker Hall & Co. (1929) Ltd								
3, 7, 29	x, y	1000 ft³/min	9 lbf/in²g 12½ in Hg vac.	Al alloy		V-rope		Oil free
18	x, y	2355 ft³/min	120 lbf/in²g 29·98 in Hg vac.	C.I. & steel		Direct coupled		Compressed air service
18		680 ft³/min	105 lbf/in²g	C.I. & Al		Direct coupled		Compressed air service
Worthington-Simpson Ltd								
3, 4, 6, 7, 8, 15, 16	a, c, d, g, h, m, s, t							
Youngs (Lifting Appliances) Ltd								
	z	Up to 15,000 lbf/in²		Aluminium, bronze, etc		Hand operated		Specials supplied with stainless steel pump

Blowers

AEI Heavy Plant Division								
30	y	800 lb/s at 7 lb differential pressure	125 lbf/in²g	Stainless blades, steel casting, class 1 welding where necessary	160°C	4000 hp motor, driven through Fluidrive coupling for starting and shutdown	AEI-JT for Berkeley	Main gas circulators, CO_2, single stage overhung type, special gas-tight running seal on blower shaft, stationary gas-tight seal
30	y	2760 lb/s	300 lbf/in²a	Fabricated spherical casing	300°C	Turbine drive with pony motor in-line for starting and shutdown	TNPG for Dungeness	
English Electric Co. Ltd								
30	y		Up to 279 lbf/in²a	Mild steels generally, alloy steels for rotating parts		Electric or steam	For Hinkley Point and Sizewell	Variable stagger inlet guide vanes, maintenance with circuit at pressure, oil or air seals, horizontal or vertical configuration
GEC Co. Ltd								
29	y	710 lb/s	150 lbf/in²		400°F	1230 V 2354 hp double armature d.c. motor	Hunterston	Centrifugal type. Crane gas seal assembly at one end of impeller shaft, leakage less than 0·03 lb/h
29	y	1522 lb/s	189 lbf/in²g		384°F	Back-pressure steam turbine	Tokai Mura	Centrifugal, single-stage, vertical shaft
James Howden & Co. Ltd								
	y	109 lb/s	270 lbf/in²g		250-325°C	1570 hp constant speed a.c. motor	AGR Windscale	Inlet vane control, high efficiency aerofoil bladed radial-flow impeller and diffuser. Blowers supplied for the original Windscale piles
C. A. Parsons & Co. Ltd								
30	y		130 lbf/in²		180°C	Variable frequency induction motors	Bradwell	Single stage axial flow (also supplying for Latina)
29	y	491 lb/s	100 lbf/in²a		284°F	Compound wound d.c. motors Ward-Leonard control system	Calder Hall & Chapelcross	Single stage centrifugal type
Richardsons Westgarth & Co. Ltd								
30	y	1500 lb/s at 15 lbf/in² differential pressure	240 lbf/in²g		200°C	6200 hp constant speed squirrel cage induction motor	Trawsfynydd	Single stage axial flow, constant speed. Flow changes accommodated by automatic by-passing and valve throttling, circulator shaft gas seal.

CONTROLLED LEAKAGE PUMPS

by RICHARD A. HAUGEN, Engineer, Fluid Dynamics Dept., Allis-Chalmers Mfg. Co.

Three pumps with improved shaft seal design for the Pathfinder BWR have been satisfactorily tested at 2000 lbf/in².

THE CONTROLLED LEAKAGE PUMP is an economical unit as its initial cost is a fraction of that of a canned hermetically sealed unit; its maintenance costs and inventory requirements are also considerably less expensive. For example, the bearings used are generally the readily available standard anti-friction type.

Overall efficiency of a controlled leakage unit is 10-15 points higher than a canned hermetically sealed unit, depending on the application. For example, the overall efficiency of the controlled leakage pump to be used in the Pathfinder plant will be about 79%. On the other hand N.S. *Savannah*, has a PWR and forced circulation is accomplished by a canned hermetically sealed unit with an overall efficiency of about 69%.

Prototype testing results

The seal for the Pathfinder prototype pump was exposed to severe operating conditions and showed no evidence of wear throughout the entire test. Twice it was exposed to high temperatures caused by malfunctioning of external equipment. As the high temperature water passed through the seal, pressure was reduced and the water flashed to steam. When flashing occurred, there was an absence of adequate lubrication. The buffer seal was affected only once by the high temperature water and that was of a minor nature. The seal arrangement exposed to this extremely abnormal condition still performed at top efficiency throughout the test without any indication of uncontrolled leakage. Figure 1 shows the pump characteristics.

Prototype drive equipment

This prototype pump, a vertical, single stage, centrifugal pump driven by a 400 hp, 2300 V, 600 rev/min induction motor, has an overhung impeller which contains a journal for a fluid piston type radial bearing. A buffer seal is mounted above the impeller sealing the primary water being pumped by this unit. A mechanical seal in series with the buffer seal serves to contain the leakage and back up the buffer seal. The motor was equipped with anti-friction bearings to take both radial and axial thrust loads. With two anti-friction bearings in the motor, one bearing had to be built into the casing to take care of the shaft extension into the casing. The fluid piston hydrostatic bearing used for this application operates on the primary fluid being pumped.

Four separated compartments are supplied with liquid under pressure through an orifice. The compartment pressures vary automatically with the load. The net effect is to provide a hydraulic restoring force tending to centre the shaft.

ADVANTAGES OF CONTROLLED LEAKAGE PUMPS

1. Fewer parts exposed to primary fluids, thus far less contamination before maintenance.
2. Motor accessible for normal care and maintenance.
3. Reduced sensitivity to high starting currents as adequate heat dissipation is available.
4. Conventional anti-friction bearings can be used which can stand more abuse than a carbon bearing.
5. Units are readily conducive to variable speed operation.
6. No external piping is required for motor cooling.

Sealing in series for self-adjustment

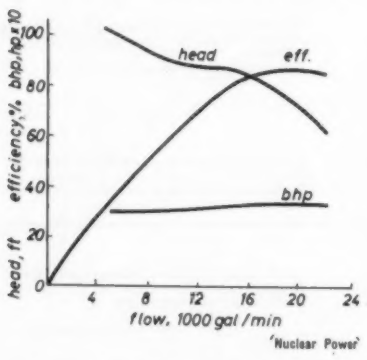
The buffer seal used in the prototype operates on a combination of two basic principles of shaft sealing. The first is a series of close fitting separately supported circumferential seals placed about a rotating shaft and the second, a face seal composed of a stationary seat and a floating sleeve face.

These two are placed in series to provide a self-adjusting, controlled leakage sealing arrangement. The seal rings provide a nominal pressure drop with the face seal taking the remaining pressure drop. As shown in Fig. 2, $A_1P_1=A_2P_2+A_3P_3$. If the rate of leakage increases, an unbalanced force is created as P_2 and P_3 become smaller. This creates an unbalanced force upwards, tending to close the gap at the face seal. As the face seal gap closes P_2 and P_3 increase until the forces balance, thus setting the position of the floating sleeve.

These close fitted seal rings operate on a full film lubrication principle. This physically separates the journal from the ring with no metal-to-metal contact. Infinitely long service life can be obtained provided a supply of clean buffer water of the right temperature and flow is continuously maintained. The radial load the seal rings sustain is kept by design to a minimum value.

A buffer type seal in a controlled leakage pump should have the following criteria: (1) The horsepower consumption should be negligible; (2) it should be able to withstand thermal shock; (3) the amount of controlled leakage should be nominal from 0·1 to 2 gal/min depending on specific design conditions; (4) long life potential with only gradual wear, detectable by observing seal characteristics; (5) holding seal length to a minimum permitting a compact design; (6) easy maintenance; (7) safety and reliability; and (8) no undue sensitivity to vibration or misalignment.

Technological advances in controlled leakage pump design in the past few years will probably lead to serious consideration of using them for circulating the water through a pressurized water reactor.



Pump characteristics obtained when operating in a system of 700lbf/in²g at 486°F. The pump was designed for a rated capacity of 20,000 gal/min and a total developed head of 71ft (Fig.1)

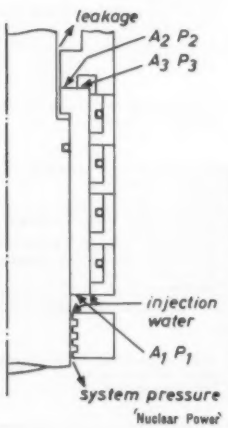


Diagram showing how the pressure differential across the seal rings allows the sleeve to respond to variations in leakage by seeking a balanced position and thus setting the amount of controlled leakage (Fig. 2)

Three years operation of the DMTR at Dounreay has thrown some interesting light on the problem of pumping liquid in closed circuits

EXPERIENCE WITH GLANDLESS HEAVY WATER PUMPS

by D. W. JAMIESON, Reactor Engineer, Dounreay Experimental Reactor Establishment

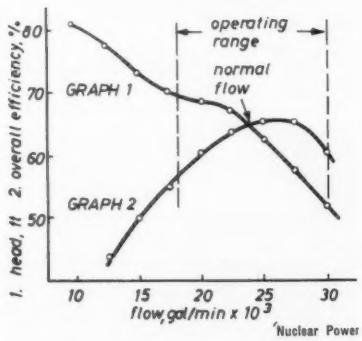
THE MAIN CIRCULATOR PUMPS are fully submersible, circulating the heavy water through the reactor core and heat exchangers in a completely closed circuit. They run at 1460 rev/min delivering 2500 gal/min at 60 ft head. The characteristic curves of a typical pump are shown in Fig. 1. The unit is mounted vertically inside a sealed casing flanged at both ends (see Fig. 2). The upper flange is bolted directly on the suction line and the lower end to the discharge line thus the casing becomes part of the circuit. The lower flange is of larger proportion and also acts as a base for mounting on a hollow stool. The heavy water flows down past the stator into the impeller and the pump bowl directs it vertically into the discharge port. The top thrust cover which also houses the stator has holes in it to allow the heavy water to flow through the windings and bearings to cater for cooling and lubricating. The double squirrel cage motor has aluminium bars and laminations of stainless steel.

Test run and circuit clean-up

On reactor commissioning, the circulators were run for the first time for two main purposes i.e. to clean-up the circuit and to test and record performances of the plant. For clean-up, demineralized water was used and temporary filters were installed up stream of the pump to catch any particulate matter left in the system during construction. These filters were of stainless steel mesh of conical shape welded to a light flange caught between the pipe flanges of the circuit.

The pumps had been running for a few days when one developed an unusual noise coupled with vibration. This circulator was immediately stopped and dismantled. The filter mesh was found wedged into the impeller blades. The components were subjected to examination but no damage could be seen so the pump was rebuilt and successfully tested. The other filters were removed from the circuit and examined. It was found that the mesh was breaking away from the flange at the welds due to embrittlement. New filters were made with better welding methods and supported direct from the flange by heavy wire stays. The circuit was then re-assembled and tested.

Process testing of the reactor then carried on with no trouble from the circulators except that if part of the circuit was drained, great care had to



Pump characteristics (Fig. 1)

be taken on refilling to ensure the bearings were immersed on start-up. The smallest quantity of gas left in the circuit could cause pick-up between the ferobestos bearing and the stainless steel journal. This could at times be sufficient to create overload on starting.

After process testing, the next stage was low power runs of the reactor. All testing before this was at normal ambient temperatures and now the heavy water could be allowed to heat up nearer to the working temperatures. The main circulators all showed excessive loading at these temperatures and one completely stopped. They were opened up for examination and the windings of the one that stopped were completely burned out and had to be replaced. Inspection of the components revealed that the clearances between the impeller sealing rings and the pump bowl were not concentric and were in contact at one side. Figure 3 shows the resultant marks on the bowl; the deepest were of the order 0·007 in. It must be pointed out that the pumps had passed extensive running tests at normal temperature and this fault only showed when run at working temperature.

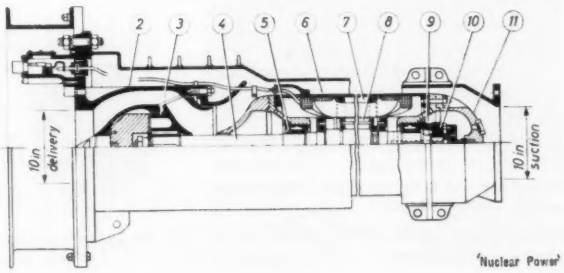
Further investigation showed that the male locating spigot on the pump body was out of truth to the centre axis and this was the direct cause of the fault. This male spigot was reduced by hand filing along the side showing the interference until the impeller was concentric with the pump bowl. On reassembly an outside locking plate was screwed on the pump bowl to make sure the body was pushed into its correct control position before tightening down on the main joint. The pumps were then replaced in circuit and gave no further trouble.

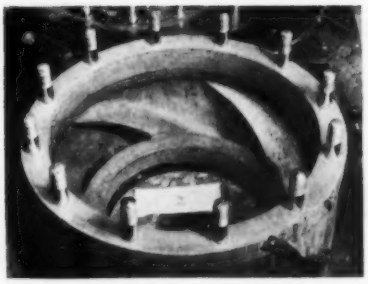
Ancillary pumps

The second type of pump in this reactor is that in which the impeller is connected to an orthodox electric motor outside the circuit by a magnetic drive, the two halves of which are separated by a thin stationary shroud (Fig. 4). During reactor commissioning,

Sectional arrangement of single low pressure water circulator (Fig. 2)

1 Outer casing; 2 Pump bowl; 3 Impeller; 4 Combined shaft; 5 Journal sleeve (ferobestos); 6 Stator shell; 7 Stator laminations; 8 Rotor laminations; 9 Top bearing shell; 10 Thrust disk (ferobestos); 11 Thrust chamber





Pump bowl scouring (Fig. 3)

a recurring fault showed in these pumps which was difficult to diagnose. The symptoms were that on stopping a pump which had been running trouble free for weeks, it would not start up again. On stripping it was found that pick-up on the bearing surfaces had occurred. This was very small and a gentle clean-up around the area sufficed to make the pump operate successfully until it was stopped again.

The first conjecture to be investigated was that gas pockets were forming in the pump and on start-up the bearings were dry. A number of tests and measurements were taken to test this theory but they were never conclusive.

It was noticed that during start-up and stopping periods the pump was subject to vibration of low frequency somewhere near half speed on acceleration and deceleration. The method of mounting this type of pump on its steel stool and the fixing of this stool to the diaphragm type floor was therefore examined. There was no easy way to strengthen these mountings to cut down this vibration so a bracket was fixed from the pump motor to steelwork adjacent to but independent of the pump mountings. This steadied the system on start-up and stop and there was no further pick-up on the bearings.

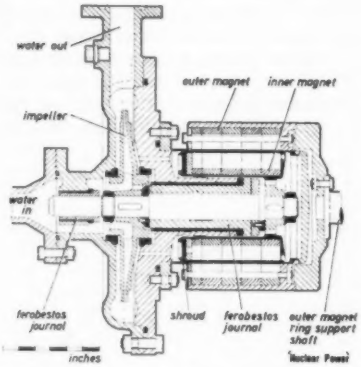
Conditions during maintenance

These troubles during commissioning were made more difficult to cure as to drain the system meant taking care in conserving the expensive high purity water. This meant taking extraordinary precautions before breaking a joint to make sure pockets of liquid were drained or if this was not practical, to set up a system to catch the heavy water as the flange bolts were loosened.

After the commissioning period was over and the reactor had been run-up to power, another difficulty in maintaining these pumps, the contamination hazard, is introduced. If it becomes necessary to strip any of these heavy water pumps after a power run the maintenance men must work under clean conditions with complete clothing change and full P.V.C. protection including air line face mask. This situation eases off after immediate stripping as the components are separated and laid out for inspection, since the concentrations of tritium are less and exposure levels fall.

These two types of pump have been in use at Dounreay for three years and once the 'shake down' period was over have given no further trouble. They are examined once per year and the bearing wear has not been measurable. Bearings have been replaced because of mild scoring and pick-up showing during these maintenance examinations (see Fig. 5).

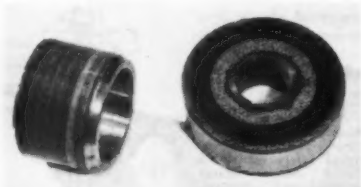
From the maintenance point of view,



Section through auxiliary pump (Fig. 4)

in future designs of this type of circuit, experience points to self-draining circuits or drainpoints of good proportion and easily connected. When a pump is put back in service after a maintenance strip down it must be evacuated to make sure no air or light water is left in the circuit which would degrade the heavy water, provision of evacuating valves should be made in all these type of circuits. These may be incorporated on the drain or vent points to advantage.

Another advantage would be built-in local ventilation with flexible points able to suck close to any part of the circuit to be broken and thus make sure that the tritium concentrations are removed. Improvements could be made in the electrical connections and glands by making them larger than normal practice dictates.



Damaged journal and thrust plate of a main circulator (Fig. 5)

Active workshops

A general disadvantage of the immersed type of pump during maintenance is the lifting height required to withdraw the outer casing from the inner unit. Being within a reactor building means this can be done easily but as the contamination rises through time it means that part of the building becomes active. The pump must be worked on during the general reactor maintenance period; therefore, working space and crane use must be programmed with all other operational and maintenance activities. The answer is to have a special maintenance area outside the building, fitted with changerooms, ventilation, wash-down and drainage facilities and a crane with suitable lifting height.

Reconditioning

On normal maintenance work it is quite common practice to send components or whole pumps back to makers for reconditioning or rewind of motors. In reactor work this is not so. After a heavy water reactor has run at power the contamination gets worse and is more difficult to remove. This means that any components requiring a service outside the scope of the active workshop must be replaced so that large spares have to be carried.

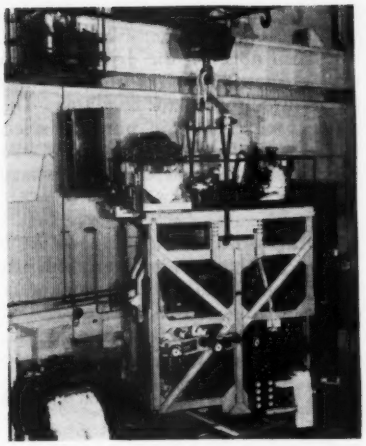
When one of the submersible units required to be rewound it was decided to send it back to the makers. The reactor had not been long in service and therefore the surface contamination count was not very high. Even so it was too high to allow outside an active area and this meant decontamination before despatch. The components were subjected to the usual process of acid wash and hot water but this did not bring it down to permitted levels. Further processing with steam and stronger acids brought down the levels sufficiently but some of the components had to be scrapped due to the harsh decontamination process required. From this experience it has been decided that in future if machining is required during maintenance to make a part serviceable, the machine tool will be protected by 'cocooning' as far as possible. It will then be brought into the active workshops and after use it will be decontaminated and returned to main shops. This is thought to be the simplest and most economical method of servicing.

In conclusion I would like to thank the designers and suppliers* of these pumps for their co-operation and help during commissioning at Dounreay and for information used in this article, and the Managing Director, Reactor Group, UKAEA for permission to publish.

* Hayward Tyler & Co. Ltd., Howard Mechanical Developments Ltd.

Component testing for Hinkley Point

Some of the more complex parts will be tested under full operating conditions in these new facilities



The charge/discharge machine weighs 250 tons when fully shielded. It is shown here in a temporary structure by which it can be lifted and placed over the test pit. The cylindrical magazine which contains the 3 ft long fuel elements is at the top left of the structure; the valve block controlling machine operation is at bottom right

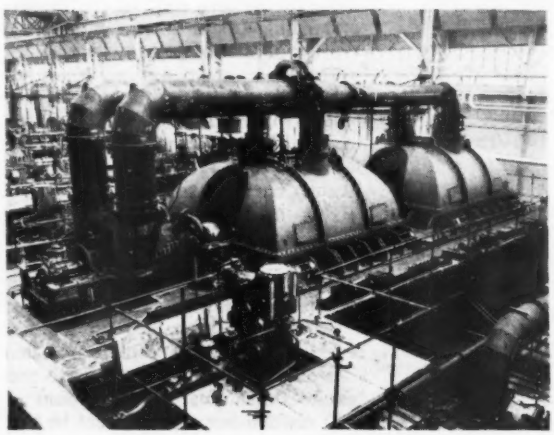
SINCE the English Electric, Babcock & Wilcox, Taylor Woodrow atomic power research centre at Whetstone was opened nearly two years ago, the charge machine test facility has been commissioned, Saturn, the largest analogue computer in Europe, is now in operation simulating power station performance, and the graphite machine shop is in full scale production (see *Nuclear Power*, Sept., 1959). *Nuclear Power* was recently invited to view these aspects of the work being carried out at the centre and also other test facilities at English Electric's turbine works at Rugby.

The centre at Whetstone cost over £1 million to build and running costs are over £2 million/year. The extensive design work carried out here and at laboratories and works of other members of the group has led to the advanced compact Sizewell design at a predicted cost of £95/kW. In contrast, Hinkley Point is reported to be costing about £120/kW. The cost reductions will in part be due to the extensive reliability testing of the actual components before they are sent to the station.

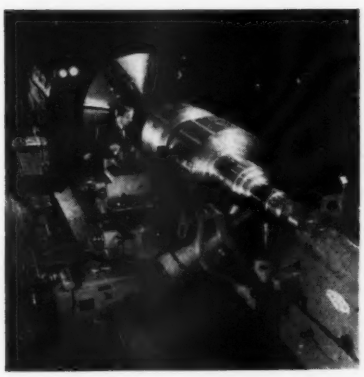
Charge machine testing

The charge/discharge machine is one of the components which must be extremely reliable if a high load factor, and thus low generating costs, is to be maintained. The Hinkley Point machines will be tested for well over a year under simulated reactor conditions. The facility consists of a 90-ft test pit in a building with 50 ft headroom containing two pressure vessels and various other tests rigs. In one vessel, a simulated group of 36 fuel channels has CO_2 at 400°C and 200 lbf/in²g flowing through it. The other smaller vessel represents the upper part of the reactor pressure vessel down to the charge pan and the first row of fuel elements. It contains static CO_2 at reactor temperature and pressure and supplements the full-scale operating facility. As well as tests on the charge machine and charge chute assembly, the effects of gas flow on fuel elements and the fuel element grab

A blower is assembled on the test bed at Rugby



The first of the 93.5 MW Hinkley Point main turbines is being prepared for test



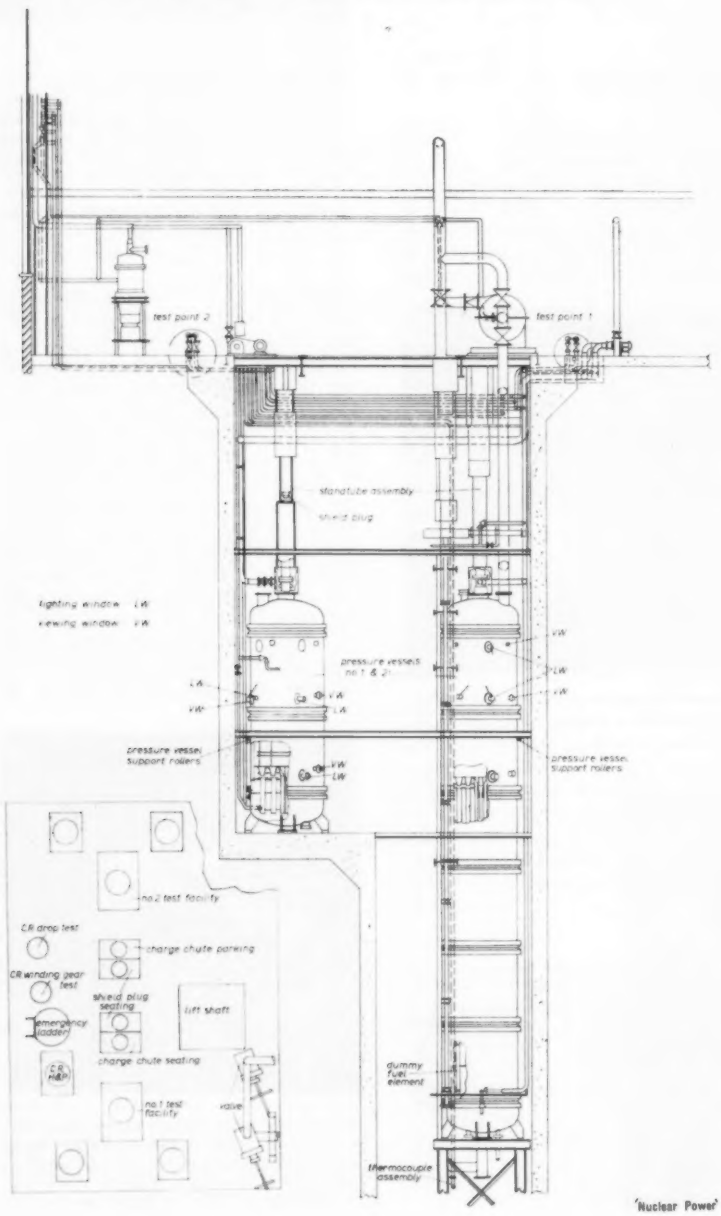
Due to the large amount of low pressure steam the main turboalternators have two double flow low pressure cylinders; here one of the rotors is being machined at English Electric's Rugby works

will be studied. Extensive work has also been done on the dry lubrication of the chute assembly which is also tested in out-of-reactor conditions. Die steels, tool steels, and nitriding steels have been found suitable for the bearing parts and graphite bushes have also been used.

Graphite machining

The graphite shop was built to machine nuclear graphite parts on a production line basis. The machining operations are carried out in sequence, using the latest unit heads built into machine setups designed at Whetstone. All dimensions of the bricks or tiles are inspected in one operation and are kept within close tolerances. The maximum output for 1961 will be at a rate of 7000 parts/week and, in all, over 300,000 parts weighing 4500 tons will be produced for Hinkley Point. The shop was laid out to give a high degree of flexibility and is able to easily accommodate core design changes. The quality of the graphite is carefully checked, using the analytical services provided by the research centre, and is sorted according to quality. The less pure is used in the flattened region. This, it is reported, results in a small increase in the power output.

Plan and elevation of the charge/discharge machine test pit



'Nuclear Power'

Hole preparation machine

A test bed in a 70 ft deep pit has been built at Rugby and operation of the first Hinkley Point machine is being checked. The operations carried out are removal of the seal plugs from the standpipes, removal of control rods and insertion of the charge chute assembly. Also being tested are the emergency devices.

Shaft and rotor alignment of one of the blowers are checked

Circulator test bed

The 12 single-stage axial blowers for Hinkley Point are being built at Whetstone by English Electric and the completed machines tested in air under atmospheric conditions at Rugby. The flow path reproduces that followed at Hinkley Point. The blower is driven by a 700 hp motor and measurements are made of pressure ratio and mass flow etc. Blowers tested to date have had identical performances. When installed at Hinkley Point they will be driven by 7000 hp variable speed induction motors and will be capable of handling CO_2 at the rate of 1 ton/s at 178°C and 200 lbf/in²g.

There are other rigs at Whetstone used for proving designs, and testing reliability of seals and bearings at reactor operating conditions.

Steam turbine test

The main turbines for Hinkley Point, six units of 93.5 MW max. capacity, are of the impulse reaction type and are characterized by the large low pressure end. The sets are produced at Rugby and assembled on the test bed. Here, together with associated control gear, they are tested up to and beyond the normal running speed of 3000 rev/min before being sent to site.

Cross Section by GRACCHUS

IT COULD perhaps have been chance that both Sir John Cockroft and Professor Vasily Emelyanov should have, within the space of a few weeks, pointed to the need for common research programmes. I personally believe this to be an indication of the way things will shape in the future.

Sir John, in his presidential address to the recently amalgamated Institute of Physics and Physical Society, stressed the importance of international co-operative efforts in providing the expensive equipment now needed for fundamental research in physics. His examples were bubble chambers, particle accelerators, large computers and equipment for space research. Sir John considered that the UK's annual expenditure on basic physical research was in the region of £7 million and that this needed to be doubled over the next ten years. Such expenditure was essential to future development.

Professor Emelyanov, in his interview with *Nuclear Power* (see *Worldview*, this issue), touched on the same theme. His example was his favourite subject —fast reactors. Expressing himself very clearly, despite an earlier remark that he had not yet mastered the English language for he had only started learning three years ago, Professor Emelyanov stressed the economies available and the possibility of quicker and possibly better results if world scientists got together over common problems.

One hopes that this casting of bread upon the waters by two eminent scientists will be rewarded. It does seem galling and pointless that expensive basic research should be duplicated when with a little more goodwill and considerably less national pride, steps could be taken to place science once again on a truly international footing.

AMERICAN INDUSTRY must be awaiting with more than formal interest the result of AEC inquiries to power reactor licensees and applicants on the stress corrosion cracking problem in 17-4 stainless steel. Also to be determined is whether this has had any effect on military reactors. Six US reactors have so far been concerned with this problem—Dresden, where the problem was brought to light, the GE's Vallecitos reactor, Elk River, Consolidated Edison (who are not to be confused with Commonwealth Edison, operators of Dresden) and its Pathfinder plant, The *NS Savannah* and BORAX V.

The cracks apparently occur when the steel has been aged at a temperature of 900°F but the problem still remains to be fully investigated. In the Shippingport PWR, for instance, cracking of this kind has not occurred. In the meantime, all the Dresden control system components of this stainless steel have been replaced by steel aged at a temperature of 1100°F; most of the Vallecitos components have been replaced; *Savannah* has had replacements ordered for chrome plated snubber seal shafts; Elk River 900°F components are to be replaced or re-treated to 1100°F; all components using this type of steel in Consolidated Edison's plant are to be replaced and action is to be taken on the cracks discovered in the drive components of Experimental Boiling Water Reactor control rod drives that were to have been used for BORAX V.

These difficulties will, no doubt, lend strength to the recent remarks by Mr E. Justin Wilson, president of American Standard's Advanced Technology Laboratories. Speaking before the Joint Committee on Atomic Energy at the '202' hearings, he said that erratic operation of control rods had been experienced on a significant percentage of operating power type reactors including BORAX, EBWR, Dresden and SL-1. He added that it seemed likely that control rods would continue to be a potential source of difficulty and when higher temperatures were encountered, the situation might be aggravated. Mr Wilson asked that AEC support be continued on the Advanced Technology project, the Variable Moderator Reactor, a light water cooled and moderated BWR. This is controlled through adjustment of the moderator level by means of ordinary process systems external to the reactor vessel.

What with these difficulties, the Supreme Court hearing on the Enrico Fermi project, and possible further AEC finance for reactor projects, it seems that US nuclear industry is in for an interesting year.

WITH BRITAIN'S entry into the Common Market apparently only a short step away, it is probably just as well to look closely at the recent report 'Trading opportunities in Europe' published by the Export Council for Europe. This first report is based on 'Pathfinder' missions to Austria, Denmark, France, Italy, Norway, Portugal, Spain, Sweden and Switzerland. It is the contention of the report that European markets are more profitable than most British firms have so far supposed. Too much of British industry has been geared 'primarily to domestic needs and traditional markets. A new adjustment is called for and time is not on our side' the publication adds.

One encouraging item for the consortia is a note that the Spanish Government expects British firms to be well in the running when large orders for nuclear power stations are placed by 1963-64 (over the next 15 years, the report says, seven nuclear power stations are to be built).

Apart from this, another feature I noted was a comment that improved arrangements for young European engineers and technologists to receive training in Britain were one excellent method to achieve a 'lasting projection of the national image'. Part, at least, of German advances in exports to Denmark, Sweden and Norway, can be traced to earlier encouragement of training visits by young technicians now assuming influence as swift promotion at home brings them power to choose the source of some national imports.

ONE OF THE problems that may prove tricky to solve for Euratom is what to do about its subsidy proposals for power reactors if Britain should join the Common Market. If the CEGB, for instance, applied to Euratom for a subsidy towards helping in the cost of manufacture of fuel elements or to underwrite the extra costs of those over conventional stations during the start-up period of one reactor, Euratom would have to chose between the Latina project and one of the CEGB stations. On the evidence of Euratom's basis for aid—size, likely contribution to the community's industrial potential and information towards lowering costs—the later stations such as Dungeness and Sizewell and perhaps the AGR should surely be strong contenders.

Graphite for fuel canning

Carbon tubes as impermeable as quartz have been made which can be shrunk-fitted on to fuel shapes

CARBON or graphite for use as a canning material requires a degree of impermeability matching that of metal or glass. A reasonable target would correspond to a transpiration of 10^{-12} st.cm³ He through a 1 cm cube for a pressure difference of 1 atmosphere.

The normal techniques of graphite manufacture which rely on the preparation of artefacts from the pitch/coke mixtures, and sometimes involve impregnation at the baked stage, appear to be unsuitable for the development of such a material. Using a mixture of materials as different as coke and pitch, a leak-tight product is unlikely; the different shrinkages of the two components lead to porosity as calcination proceeds and similar difficulties apply to the impregnation process. A surface coating obtained by pyrolizing carbonaceous vapours is undesirable since it produces a product which relies on an impermeable skin; such skins have been shown prone to penetration (*1*).

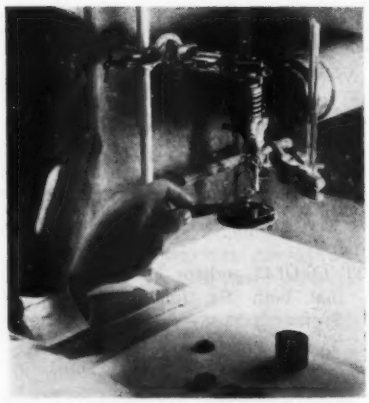
To overcome this problem an attempt was made to manufacture the carbon from a homogeneous organic starting material. The basic idea underlying the process stems from the fact that certain non-graphitizing carbons undergo a marked degree of pore closure following heat treatment at graphitizing temperatures. The helium density of the material treated to 1000°C has a value of 2·05, but this drops to 1·45 on graphitization. In addition, there are no anomalous changes in crystal or bulk densities. Relying on a carbohydrate starting material, shapes are slip cast from aqueous suspensions using a centrifugal process since this effectively avoids porosity arising from air entrainment. After the slip cast product is dried it can be conveniently machined to shape. This is an advantage since the machining treatment will always ensure that the decomposition products need not traverse unnecessary distances on baking.

An essential part of the process consists of ensuring a very fine pore structure at all stages. The final pore closure is regarded as a sintering process in which crystals grow and bridge the pores thus achieving complete impermeability. This pore closure must be deferred until all volatile matter has escaped. It is also important that the organic starting material should not go through a liquid state during the heat treatment; melting of the material affects the initial pore structure drastically and causes pore blockage which impedes the flow of decomposition products and results in the disruption of the carbon. Heat treatment is normally carried out in three stages and more than 50% by weight of the starting material has to be expelled through the fine pores of the residue without building up any undue strains which could lead to cracks.

> The GEC has long experience in carbon and graphite development. For some ten years mechanical properties have been studied, and, more recently, irradiation effects. With interest in graphite as a canning material, research commenced in 1957 to reduce its permeability. Using an aqueous sugar solution, a plant was commissioned in 1960 capable of impregnating 2000 sleeves per week. A small laboratory pilot plant also exists for the preparation of a completely impermeable graphite which behaves as a metal.

Leak tests on tubes 4 in long × 0·020 in thick × 0·5 in dia. show no transpiration of helium at 10^{-7} lusecs. At present, the small laboratory pilot plant developed is suitable only for the manufacture of tubular cans of limited dimensions and the preparation of experimental material. Insufficient specimens have been available for a proper study of the physical properties. The product is not a high density graphite but bulk densities up to 1·65g/cm³ have been achieved. The specific electrical resistance is about 4×10^{-3} ohm cm. The material has a very small crystal size and can be characterized by values 70A, 80A and 0·9 for L_c, L_a and p respectively. The elastic moduli and the strength of the material are in accordance with the low degree of crystal perfection. A tensile strength of 10,000 lbf/in² is a realistic target in production and there are grounds for believing that with process optimization a strength of 20,000 lbf/in² can be attained.

For irradiation, graphite springs are sealed in a quartz bulb (Fig. 2)



Temporary displacement of the atomic structure of graphite by neutrons causes creep. This effect compensates for the normal brittle nature of the material by providing a relief for the stresses which build up under irradiation. Stress levels are studied by measuring the separation between the turns of a graphite spring, supporting a weight (Fig.1)

Because the carbon tubes produced by this process can be shrunk-fitted on to fuel shapes, the expensive grinding and machining processes necessary to attain the correct clearance between the fuel and the can are no longer necessary.

In addition to developing impermeable graphite techniques, the Hirst Research Centre has carried out considerable research on neutron irradiation induced creep, the initial results of which were reported at Geneva (*1*). Specimens irradiated in a reactor under a pre-selected atmosphere show that at small doses (1000 MWd/t) stresses which may accumulate within a moderator brick can be relieved by irradiation. Current work is aimed at providing data for more severe neutron doses. The specimens employed in these studies take the form of four graphite springs sealed in a quartz tube (Fig. 2). Each of the springs carries a weight and they are suspended in series so that each spring carries those beneath it. Four stress levels therefore can be studied simultaneously.

Reference
1. 2nd Geneva Conference 1958. Paper 303.

Some typical figures for the safety and serviceability of a system containing several functional groups of channels are established

Safety and serviceability in reactor safety circuits—2

by U. BROCCARDO, Dott. Ing. Nuclear Department, Kennedy and Donkin

IN THE FIRST ARTICLE a new definition of safety and serviceability of electronic equipment was proposed, a theory was developed and this was applied to the case of a single guard line. The same theory is now extended first to a single group of channels and then to whole safety system and the parameters on which serviceability and safety depends are investigated.

SINGLE FUNCTIONAL GROUP OF CHANNELS

When the principles of redundancy and coincidence are applied, the mathematical expression of the probability should show, on the one hand, the increase in the fault probability due to the increased number of instruments monitoring the same function and on the other, the decrease in the number of spurious trips (serviceability case) due to the required coincidence of faults to trip the reactor. An improvement can be expected if the first effect is overcome by the second.

Let us first consider the idealized case of a single functional group of channels, or, in other words, of a single trip function monitored by more than one detector. If f_c is the channel safe fault rate, t_s the duration of a safe fault and p_c the safe fault probability for the channel, equation (2) becomes:

$$p_c = t_s f_c \qquad (2')$$

Taking the 2 out of 3 trip arrangement as an example and calling *A*, *B* and *C* the three channels, a spurious trip will be caused by a coincidence of safe faults either in *A* and *B* or in *A* and *C* or in *B* and *C*. By applying the multiplication and the addition law for probability, the fault probability for the group will be:

$$p_g = 3p_c^2 = (3C2)\, p_c^2 \qquad (13)$$

where $3C2$ stands for the number of combinations of 3 elements in groups of 2.

The numerical factor caters for the increased number of faults and derives from the application of the addition law; the power is the mathematical expression of the coincidence and derives from the multiplication law.

The corresponding expression for unsafe faults is:

$$q_g = 3q_c^2 = (3C2)\, q_c^2 \qquad (14)$$

with obvious meaning of the symbols.

For other arrangements (13) and (14) would differ, as will be seen below.

Serviceability aspect

If the trip arrangement is *r* out of *m*, it can be seen that the general expression for the probability of a spurious trip is:

$$p_g = (mCr)\, p_c^r \qquad (15)$$

where mCr stands for the number of combinations of *m* elements in groups of *r*.

As well as considering the safety and serviceability of a complete safety system containing several functional groups of channels the improvements that can be made in safety by 'double' systems, which eliminate cross-function trips, and by 'backing-up' are discussed. Improvements in serviceability which are brought about by splitting the system are also outlined. The third and final article will deal with the economics of the problem.

The question which now arises is how to go back from this probability to the expected occurrences of trips. According to the definition, to obtain these, one should multiply the probability by the number of trials. For a period of a year and for the case of a single instrument or a single line, this is simply $\frac{1}{t_s}$, i.e. the inverse of the safe fault duration expressed as a fraction of a year.

However, to speak of the average duration of a trip does not make sense. The difficulty can be avoided by drawing attention to the fact that the event causing a trip is a coincidence of hours during which there is a safe fault. It seems reasonable therefore to assume the number of trials again equal to the number of hours in one year (if a period of one

year is considered), or, more generally, to $\frac{1}{t_s}$, where t_s is a fraction of year.

It should be considered that the instrument (or channels) of the group work simultaneously and the (working+faulty) time of the group is still one year, not m years. The individual times of the instruments are in a certain way squeezed together.

Therefore the expected occurrences of spurious trips for the group will be:

$$f_g = (mCr)\, p_c^r \frac{1}{t_s} = (mCr)\, f_c^r t_s^{r-1} \qquad (16)$$

To obtain serviceability one must further multiply by 20.

Safety aspect

For the 2 out of 3 arrangement, the expressions for the probability of faults are similar for both aspects; for other arrangements they are usually different.

In fact, taking the case with the 3 out of 4 trip arrangement, while the coincidence of three safe faults is necessary to cause a spurious trip, the coincidence of only two unsafe faults will be sufficient to engender an unsafe condition, i.e. to prevent the group tripping the reactor if required to do so.

Calling A, B, C and D the four channels, a coincidence of unsafe faults in either AB, AC, AD, BC, BD, or CD will cause an unsafe condition. If g_c is the unsafe fault rate for the channel, q_c the unsafe fault probability for the channel and q_g the unsafe fault probability for the group, by applying the multiplication and addition law for probability, one obtains for the group:

$$q_c = g_c t_u \qquad (17)$$

$$q_g = 6q_c^2 = (4C2)q_c^2 \qquad (18)$$

It can be shown that for an r out of m arrangement the expression is:

$$q_g = [mC\,(m-r+1)]\, q_c^{m-r+1} \qquad (19)$$

As for the serviceability aspect, to go back from this probability to the expected occurrences of unsafe (=dangerous) conditions during one year, it will be sufficient to multiply equation (19) by $\frac{1}{t_u}$:

$$g_g = [mC\,(m-r+1)]\, q_c^{m-r+1} \frac{1}{t_u} = [mC\,(m-r+1)]\, g_c^{m-r+1} t_u^{m-r} \qquad (20)$$

To obtain safety one must further multiply by 20.

SAFETY SYSTEM

The safety system contains several functional groups of channels or, more precisely, it is built up of a number of safety or guard lines, the outputs of which are arranged in a coincidence circuit. It includes all the equipment from the primary detector (e.g. ion chamber) to the final break contactor, which releases the shut-down devices. Figure 1 is a very much simplified version for a 2 out of 3 arrangement, the term safety circuit referring to the physical layout of the system.

In this context the scram button has to be considered as a channel, with its own safe and unsafe fault rate, a safe fault being, for example, a wrong action of the operator to shut down the reactor.

To say that the safety system has a certain degree of serviceability and safety means, in practice, that the final break contactor (in the control rod motor low frequency supply) considered as the output of the system is affected by a certain number of safe and unsafe faults, i.e. it will cause a certain number of spurious trips and dangerous conditions by opening when unnecessary and not opening when necessary.

The final break contactor will have its own safe and unsafe fault rate and all the safety system can be expected to do is not to make the situation worse.

The theory developed for the single functional group of channels can be applied to the safety system, considering that the line fault rate has the same function for the system as the channel fault rate has for the functional group of channels.

Serviceability aspect

The probability of spurious trips for the safety system can be obtained by introducing (5) in (15).

$$p_s = (mCr)\, p_l^r \qquad (21)$$

To obtain the expected occurrences it is sufficient to multiply by $\frac{1}{t_s}$ as usual:

$$f_s = (mCr)\, p_l^r \frac{1}{t_s} = (mCr)\, f_l^r\, t_s^{r-1} \qquad (22)$$

Equation (22) caters for the possibility of cross-function spurious trips, as it can be seen by introducing the n_1, n_2 and n_3 channels with fault rates f_1, f_2 and f_3. To avoid unnecessary complications to the mathematics the guard line monitoring relay safe fault rate, f_r, will be taken into account considering every relay as an additional good channel, as suggested by equation (4). For a 2 out of 3 arrangement one gets:

$$f_s = 3t_s\,(n_1f_1+n_2f_2+n_3f_3)^2 = 3t_s\,(n_1^2f_1^2+n_2^2f_2^2 + n_3^2f_3^2+2n_1f_1n_2f_2+2n_1f_1n_3f_3+2n_2f_2n_3f_3) \qquad (23)$$

The squares and the double products between brackets are the mathematical expression for the cross-function trips. For instance, the term $n_1^2f_1^2$ caters for the cross function trips within the group of good quality channels; $n_2^2f_2^2$ and $n_3^2f_3^2$ do the same for the groups of medium and poor channels respectively; $2n_1f_1n_2f_2$ caters for the spurious trips arising between the group of n_1 good channels and the group of n_2 medium channels etc.

A better appreciation of the problem may be obtained from a numerical example.

Data: $n_1=20$, $f_1=0{\cdot}1$; $n_2=3$, $f_2=1$; $n_3=3$, $f_3=10$
$t_s=10^{-4}$a

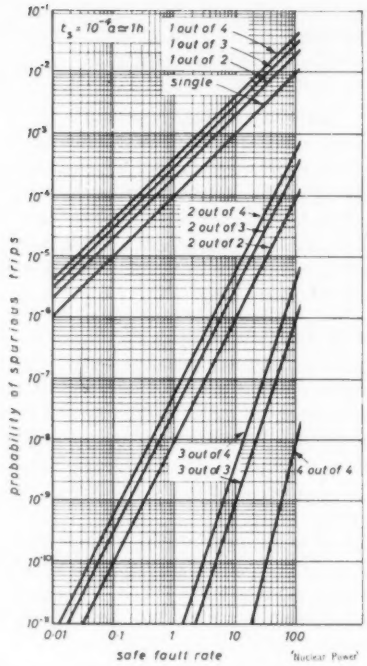
For a single line it would be: $f_l=f_s=35$.
For a 2 out of 3 it will be: $f_s=3\times35^2\times10^{-4}=0{\cdot}367$.
For 20 years this means 700 and 7 spurious trips respectively.

Safety aspect

A situation similar to the cross-function trips does not occur in this case, as every functional group of channels works independently as far as coincidence of unsafe faults is concerned.

The guard line monitoring relay unsafe fault rate can be catered for under the form of equation (10) and, to avoid complications to the mathematics, this term can be supposed to be already included in the value of g_1, g_2 and g_3. However for $g_r=0{\cdot}01$ and $t_u=10^{-2}$a, it is equal to 10^{-6} fault/a and it can therefore be neglected.

Therefore, first q_g is separately calculated for one group of good, medium and poor channels; then the three different values are multiplied by the number of group of channels of



Spurious trip probability for various arrangements (Fig. 3)

each class existing in the safety system, i.e. by n_1, n_2 and n_3 respectively. This procedure is nothing but the application of the addition law for probability.

$$q_s = q_g^{(1)} n_1 + q_g^{(2)} n_2 + q_g^{(3)} n_3 \qquad (24)$$

Introducing the unsafe fault rates and re-arranging:

$$q_s = [mC(m-r+1)]\, t_u^{m-r+1} (g_1^{m-r+1} n_1 + g_2^{m-r+1} n_2 + g_3^{m-r+1} n_3) \qquad (25)$$

Multiplication by $\frac{1}{t_u}$ will give the expected occurrences:

$$g_s = [mC(m-r+1)]\, t_u^{m-r} (g_1^{m-r+1} n_1 + g_2^{m-r+1} n_2 + g_3^{m-r+1} n_3) \qquad (26)$$

With the same value for n_1, n_2 and n_3 and assuming $g_1 = 0{\cdot}01$, $g_2 = 0{\cdot}1$, $g_3 = 1$ and $t_u = 10^{-2}$a, the figures obtained for expected occurrences of dangerous conditions in 20 years are 70 for the single line, and about 2 for the 2 out of 3 arrangement.

TABLE I

TRIP ARRANGEMENT	PROBABILITY OF SPURIOUS TRIPS	EXPECTED OCCURRENCES OF SPURIOUS TRIPS	PROBABILITY OF DANGEROUS CONDITION	EXPECTED OCCURRENCES OF DANGEROUS CONDITIONS
single	p	f	p	f
1 out of 2	$2p$	$2f$	p^2	f^2t
2 ,, 2	p^2	f^2t	$2p$	$2f$
1 ,, 3	$3p$	$3f$	p^3	f^3t^2
2 ,, 3	$3p^2$	$3f^2t$	$3p^2$	$3f^2t$
3 ,, 3	p^3	f^3t^2	$3p$	$3f$
1 ,, 4	$4p$	$4f$	p^4	f^4t^3
2 ,, 4	$6p^2$	$6f^2t$	$4p^3$	$4f^3t^2$
3 ,, 4	$4p^3$	$4f^3t^2$	$6p^2$	$6f^2t$
4 ,, 4	p^4	f^4t^3	$4p$	$4f$

The preceding results are summarized in Table 1 for some of the practical trip arrangements; Indices have been omitted for sake of simplicity.

From Table 1, assuming for the parameters values of $t_s = 10^{-4}$a and $t_u = 10^{-2}$a, the graphs in Figs. 3 and 4 have been plotted for practical fault rate values. They allow an immediate appreciation of the differences between the arrangements as well as providing an alternative means for calculating serviceability and safety.

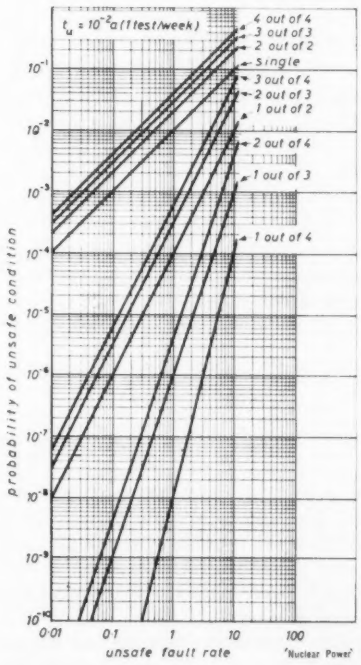
From the table and the graphs it is also clear that these are conflicting requirements and that the optimum should be reached for arrangements like 2 out of 3, 3 out of 5 etc., for which the mathematical expression is the same for both serviceability and safety. Arrangements like 2 out of 2, 2 out of 4, 3 out of 4 etc., can also be of practical interest, if one or the other aspect is stressed.

COINCIDENCE CIRCUIT

Figure 5 shows how the coincidence circuit may be realized by relay contacts: the idea is to make allowance for all the mCr combinations giving a trip. The fact that the individual contacts of the same relay may be failing at different times introduces an asymmetric component in the calculations which has not been taken into account for sake of simplicity.

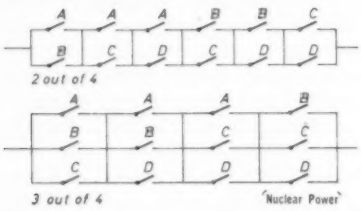
For complicated coincidence circuits, the use of static switches becomes more attractive. In place of electromagnetic relays, transistors can be used. Computer techniques have developed AND and OR gates using transistors, by means of which coincidence circuits can be built, as shown in Fig. 6 for a 2 out of 3 arrangement.

Since these devices have no moving parts or contacts there is promise that they will be more reliable than electromagnetic relays. The main difference is that relays can be designed to have a strong tendency to failure in one direction and the consequences of this can be covered by a suitable circuit design as described. With transistors and other static switching devices there is no such tendency to fail in one direction and



Unsafe condition probability for various arrangements (Fig. 4)

so there is no fail safe tendency. Testing of the devices to check that they are working correctly becomes then of paramount importance.



Two examples of coincidence circuits using electromagnetic relay contacts (Fig. 5)

THE 'DOUBLE' SAFETY SYSTEMS

The result obtained for the safety case suggests that the elimination of the cross-function trips should improve the performance of the system considerably. This is achieved by the so-called ' double ' systems, of which Fig. 7 is an example of the 2 out of 3 arrangement using electromagnetic relays.

The expression obtained for f_s in this case is:

$$f_s=(mCr)\,t_s^{r-1}\,(f_1^{r}n_1+f_2^{r}n_2+f_3^{r}n_3) \qquad (27)$$

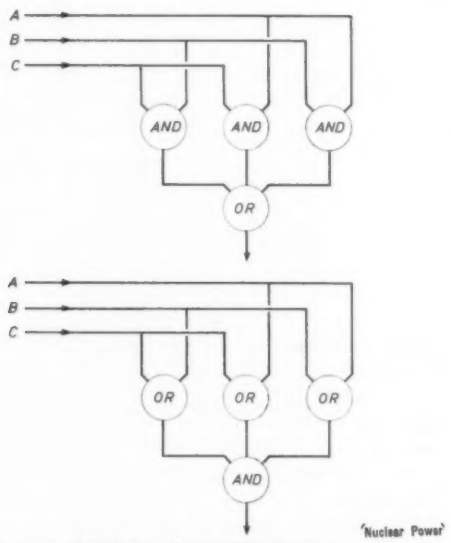
With the same data of the preceding example, the result for a period of 20 years is about 4.

The improvement in respect of the simple 2 out of 3 system is not as much as could have been expected.

The fact that the same relay is now operating a larger number of contacts causes the asymmetry factors referred to above to become important in this case and a slight worsening of the degree of safety of the system can probably be expected.

SPLITTING THE SYSTEM

Splitting of the system (i.e. of every guard line) into two smaller systems, assigning to every one a certain number of



Alternative ways of realising a 2 out of 3 coincidence circuit by means of OR and AND gates (Fig. 6)

channels, has also been suggested to improve the situation in respect to serviceability.

The application of the theory demonstrates that an improvement can be obtained in this case, only if a coincidence factor is present. As the square of the line safe fault rate appears in equation (22) for a 2 out of 3 arrangement, elementary algebra shows that:

$$(f_1^{I}+f_1^{II})^2>(f_1^{I})^2+(f_1^{II})^2 \qquad (28)$$

The best way of splitting is the one for which $f_1^{I}=f_1^{II}$.

SHORTING OUT FACILITIES

During maintenance and during the routine test the channels may or may not be shorted out. So far it has been implicitly assumed that the faulty channels were not shorted out during maintenance, but that they were shorted out during the routine test. If the opposite procedure is adopted, the consequences on serviceability and safety are remarkable and are examined separately below.

Maintenance shorting out

The purpose of shorting out the faulty channels is to enhance serviceability, as the value of t_s will thus be reduced from the time taken to repair a fault to the time required to put in the shorting plug. However this procedure adversely affects safety, as, e.g. in the 2 out of 3 arrangement, a dangerous condition could arise, should the following coincidence of events take place:

1. A safe fault in one of the three channels of a group.
2. An unsafe fault in one of the two remaining channels of the group during the repair time.
3. A reactor fault involving the same functional group of channels during the repair time.

It appears that (1) is equivalent to having an unsafe fault lasting the repair time in one of the channels of the group, i.e. the shorting out procedure transforms a safe fault into an unsafe one. The unsafe fault rate for the channel will now be:

$$g'_c=g_c+f_c \qquad (29)$$

To avoid ambiguity, the time taken to repair a fault will be indicated in this context by t_v and it is clear that t_v can assume two values, that is, zero or t_s.

By applying the addition law the relevant probability is obtained:

$$q'_c=g_c t_u+f_c t_v \qquad (17')$$

The expected occurrences for the case of a single channel are given by equation (29). Alternatively, if one wishes to work out equation (29) from equation (17'), it is clear that, what has been assumed so far to represent the number of trials and was in the previous cases simply $\frac{1}{t_u}$ will now be:

$$\frac{g_c+f_c}{g_c t_u+f_c t_v}=\frac{1}{\frac{g_c}{g_c+f_c}t_u+\frac{f_c}{g_c+f_c}t_v}=\frac{1}{t_{u,\,v}} \qquad (30)$$

The denominator of equation (30) is the weighted mean of t_u and t_v, with the weights g_c and f_c respectively. This conclusion can be regarded as general for the case of coincidence of events occurring with different frequencies and having different durations.

For the 2 out of 3 arrangement and with the same values as the previous examples for the number of channels, safe and unsafe fault rates, t_u and t_s, the calculation gives:

$$g'_1=0{\cdot}11 \quad g'_2=1{\cdot}1 \quad g'_3=11 \quad t_{u,v}=10^{-3}\text{ a}$$
$$g'_s=3\times10^{-3}(0{\cdot}11^2\times20+1{\cdot}1^2\times3+11^2\times3)=1{\cdot}1$$

For 20 years this gives 22 expected unsafe conditions, to be compared with the previous figure of 2. This suggests that shorting out during maintenance is not a recommendable procedure.

Routine test shorting out

The procedure envisaged for routine test is to inject a signal as near as possible to the detector and to check that the guard line contact opens. This can be done for example by lowering the trip level setting of the given channel. The whole operation

should not take more than a few seconds, the time necessary to ascertain that the guard line contact operates correctly. Therefore, in case the channel be shorted out, the occurrence of the above mentioned coincidence of events would be restricted to these few seconds and its probability should be negligible.

Should it be preferred to leave the line tripped during the few seconds necessary to test every channel, the total time the line would be tripped could be of the order of a minute, say 10^{-5}a. Depending on the frequency of the test, this will affect serviceability, as it would be equivalent to a safe fault once a week or once a day in every guard line. The theory will be applied under the following assumptions:

1. The routine test will be carried out at random intervals and f_t will only represent the average of the different durations.
2. Instead of n safe faults of duration 10^{-7} a, (i.e. a few seconds), a single safe fault of duration $t_t = 10^{-5}$a, (i.e. a few minutes), will be assumed to represent the effect of a test on a guard line.
3. If there is a safe fault in a guard line, the test will be postponed. This halves the times a coincidence of safe faults and test periods can take place, as in the long run a safe fault will occur first as many times as a test will do.

With reference to the same 2 out of 3 arrangement as above, the calculation will be as follows:

$$f'_1 = f_1 + f_t = f_1 + \frac{1}{2}\frac{1}{t_u} \qquad (4')$$

$$p'_1 = f_1 t_s + f_t t = f_1 t_s + \frac{1}{2}\frac{1}{t_u} t_t \qquad (5')$$

The probability of the coincidence of events is given by the square of equation (5′), the expansion of which yields three terms. The first, $f_1^2 t_s^2$, represents the probability of coincidence of safe faults in two different lines. The second, $2f_1 t_s f_t t_t$, refers to the coincidence of safe faults in one line with test periods in another and vice versa; condition (3) above enables us to divide this term by two. The third term, $f_t^2 t_t^2$, refers to the coincidence of test periods in two different lines and therefore does not apply. Hence:

$$p'_s = 3\,(f_1^2 t_s^2 + f_1 f_t t_s t_t)\quad f \qquad (21')$$

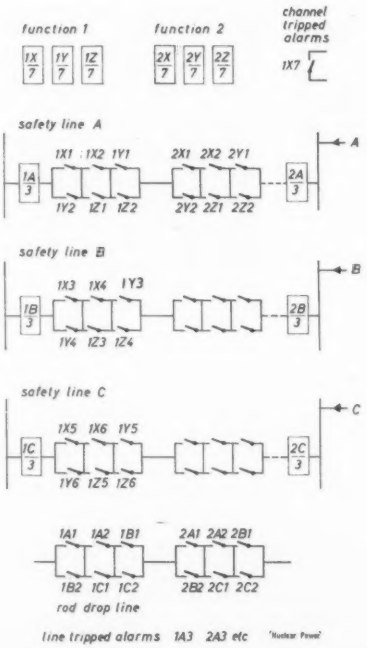
$$'_s = 3\,(f_1^2 t_s^2 + f_1 f_t t_s t_t)\frac{1}{t_{s,\,t}} \qquad (22')$$

where

$$t_{s,\,t} = \frac{f_1 t_s + f_t t_t}{f_1 + f_t} \qquad (31)$$

For $f_t = 52$ test/year, i.e. $t_u = 10^{-2}$a, and the usual values for the other symbols, one gets $f'_s = 0{\cdot}9$, i.e. 18 spurious trips in 20 years. For $f_t = 365$ test/year, i.e. $t_u = 10^{-3}$a, the result is $f'_s = 5$, i.e. 100 spurious trips in 20 years (compared with the figure of 7 previously obtained).

Therefore, to leave the line tripped during the routine test does not seem a good procedure. However, it is possible that assumption (1) is rather pessimistic.



'Double' 2 out of 3 safety circuit using electromagnetic relays (Fig. 7)

THE 'BACKING UP' PHILOSOPHY

An improvement of the degree of safety of the system is obtained by requiring that every reactor fault for which the reactor trips be detected by two types of primary detecting elements, one acting as a 'back up' of the other.

Fuel element excess temperature channels are usually regarded as a 'back up' feature for the gas cooled reactor. This is because the prevention of an undue rise in fuel element temperature is the most basic reactor protection requirement and any protective device which can anticipate such a temperature rise is preferable to one which has to wait for the rise to take place, before tripping can be initiated.

To fit this feature into the preceding theory one must consider it as a further coincidence factor.

In other words, to have an unsafe condition, which has been pessimistically assumed to be a dangerous condition all the time, one must now have a coincidence of faults first within the group and then between two groups of channels.

Having therefore the unsafe condition probability for one group of channels (good, medium or poor), one must multiply it by the unsafe condition probability of the 'backing up' group of channels. This has to be done for every group of channels, i.e. may be done directly for the whole system, once the unsafe condition probability for it without 'backing up' features has been calculated.

The fuel element excess temperature groups of channels will in turn be 'backed up' by another group of channels, e.g. the channel gas temperature one or the hot duct temperature one.

DEFINITIONS

Functional group of channels A trip function can be monitored by more than one detector, i.e. can be associated with a group of channels, whose output are usually connected in a coincidence circuit.

Cross-function trips The spurious trips caused, for example in the 2 out of 3 arrangement, by one functional group of channels having a safe fault in one safety line and another functional group having a safe fault in another line.

Unsafe condition Not all possible faults can be made self-detecting; some are left undetected and are therefore called *unsafe faults*. They can only be detected by *routine tests*. The occurrence of unsafe faults causes the reactor to be operated in an unsafe condition.

Dangerous condition If part of the instrumentation in an unsafe condition is required to operate (as in a true reactor fault) a dangerous condition may occur. Unsafe conditions do not involve financial losses, dangerous conditions do.

This 20 MW graphite moderated, uranium monocarbide fuelled and diphenyl cooled reactor concept using a direct power conversion cycle is claimed to be competitive with conventional steam plants

Direct cycle diphenyl reactor

THIS NEW REACTOR CONCEPT was developed by the US Marquardt Corporation who have been working on it for over a year and now have a proposal under active consideration by the USAEC. The system is claimed to be an advance on the OMR concept because of the use of a direct conversion cycle and the graphite clad fuel element which has a long life, excellent temperature characteristics, as well as providing moderation. By absorbing gamma radiation and displacing coolant from the core, diphenyl decomposition is greatly reduced. Considerable economies are claimed due to the direct cycle and reduction of structural steel costs arising from the use of low pressure non-corrosive working fluid. Reduced turbine costs result from the good thermodynamic properties of diphenyl which allow lower inlet pressures, lower rotor speeds, fewer stages, etc. The diphenyl is flashed outside the core with only a slight loss in efficiency thus avoiding problems associated with boiling in the core. The vapour is expanded without condensation in the turbine, and the superheat in the exhaust is removed and recovered by a conventional heat exchanger which heats the condensate returning to the reactor. Heat rejection at 250°F, or higher, means that water is not required for condenser cooling and also offers the possibility of further cost savings by the sale of waste heat at useful temperatures. Coolant make-up costs are minimized by using graphite and by the thermal barrier in the reactor vessel which reduces the volume of hot diphenyl above the core.

REACTOR DATA

Net electrical output, kW	20,000
Net cycle efficiency, %	31
Reactor vessel height, ft	28
Reactor vessel diameter, ft	10
Core height, ft	8
Core diameter, ft	8
Number of fuel elements	354
Fuel rod diameter, in	0·5
Triangular lattice pitch, in	2·78
U-235 enrichment, %	1·55
Fuel loading, kg of U-235	64
Initial conversion ratio	0·505
Coolant flow rate, lb/h	5,584,000
Core pressure drop, lb/in²	28
Average coolant temp. rise °F	57
Max. surface temp., °F	900
Average surface temp., °F	851
Average coolant velocity, ft/s	15
Average heat flux, Btu/h ft²	46,800
Max. heat flux, Btu/h ft²	113,000

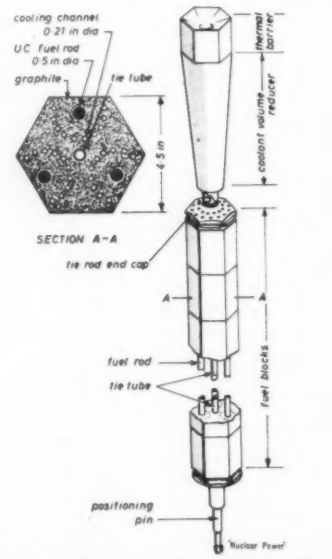
Working fluid

Diphenyl, $C_{12}H_{10}$, is an aromatic hydrocarbon of molecular weight 154. It melts at 156°F and boils at 491°F. At the maximum fuel element surface temperature the vapour pressure is 330 lbf/in²a. The diphenyl radiolysis rates are identical to that of terphenyl though its thermal stability is somewhat greater. In addition, it has low neutron absorption, negligible corrosion of structural materials, relatively low vapour pressure and negligible neutron activation. The thermodynamic properties enable a simple turbine of relatively few stages to be used and vapour extraction, moisture extraction or reheat stages are not required.

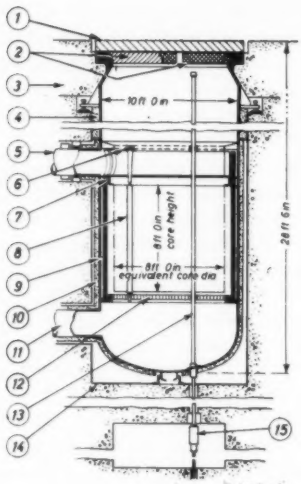
Reactor design

Coolant enters the core at the bottom and then flows upwards through the fuel elements and between the core and the thermal barrier to a plenum chamber formed by the core and modular thermal barrier above the core. The thermal barrier minimizes the volume of hot diphenyl and thus reduces pyrolysis. The core tank above the barrier is filled with cold diphenyl (400°F) and provides biological shielding. About 15% of the active core volume is diphenyl which also acts as reflector. The core is surrounded by an annular steel thermal shield and a steel grid plate supports the core and positions the fuel elements.

Nineteen of the 373 hexagonal positions in the core will be provided with dry, control-safety rods. These will be actuated from below by magnetic drives avoiding interference with fuel handling. The control rods can be replaced from the top of the core tank.



Fuel elements consist of eight one foot high fueled hexagonal sections positioned on a central tie rod. Each fuel rod is surrounded with ten coolant channels each of dia. 0·21 in



Cross-section of the reactor

1 Reactor vessel cover plate; 2 Fuel handling rotating shield assy.; 3 Concrete biological shield; 4 Core tank; 5 Coolant outlet; 6 Thermal barrier; 7 Fuel element peripheral retainer ring; 8 Fuel element (354 req.); 9 Thermal shield; 10 Insulation; 11 Coolant outlet; 12 Grid plate; 13 Control rod thimble (19 req.); 14 Cavity liner; 15 Control rod drive

Slightly subcooled liquid leaves the reactor at 850°F/330 lbf/in²a and enters the flash separator where 16% is flashed to vapour at 830°F/267 lbf/in²a. This saturated vapour is then sent to the turbine where it is expanded to superheated vapour at 663°F/0·5 lbf/in²a. It is then desuperheated in a regenerator which recovers 53% of the heat in the turbine exhaust above the condensate enthalpy. The saturated vapour is then condensed and subcooled 10°F at 0·3 lbf/in²a, pumped to the flash separator pressure and heated to 588°F in the regenerator. It is then mixed with the rest of the diphenyl which left the flash separator and returned to the reactor at 793°F/358 lbf/in²a.

Safety features

Fission product retention is provided by a triple barrier. The fuel will be coated with a material such as niobium suitable for the maximum temperatures envisaged. The graphite cladding will serve as a diffusion barrier and lastly the graphite-coolant interfaces will be coated with pyrographite.

The low operating pressures reduces potential damage due to failure of ducting or seals. Also as there is no water in the system there is no danger of high pressures due to leakage into the coolant system. Coolant losses result, moreover, in reduction of reactivity. Studies show that the DCDR has a negative coefficient of reactivity which is large enough to ensure reactor stability during load changes and transients.

Marquardt reports that the work done to date has been of a component nature with emphasis mainly on materials studies. A boiling and condensing organic loop has been successfully operated over a sustained period at well over 800°F.

Reference

Direct cycle diphenyl reactor. D. W. Bareis and G. S. Leighton. The Marquardt Corporation, Nuclear Systems Division. Paper presented to the ANS Winter Meeting, December 1960.

Experimental gas blower for EDF

variable pitch blades

An experimental variable pitch blade axial blower, suitable for use in the nuclear power stations that will follow EDF2, has been constructed for Electricité de France by the Societé Nationale d'Etude et de Construction de Moteurs d'Aviation (SNECMA). Giving a maximum output of 638 lb/sec and designed to work with CO_2 at 363 lbf/in² and 200° C, this blower, now under test at Melun-Villaroche, is a single-stage type driven by an electric motor adapted to give a constant speed of 3000 rev/min (Fig. 2).

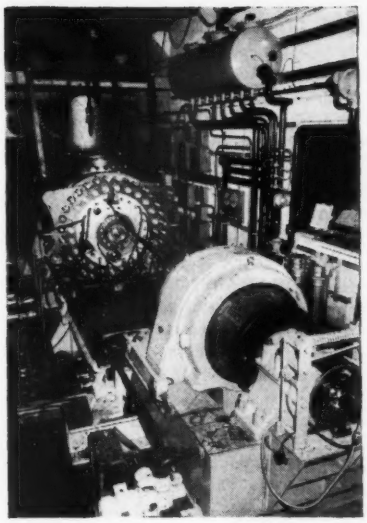
To limit the driving power, the design includes only three rotor blades (Fig. 3); continuous variation in CO_2 flow from 0 to 100% is obtained by changing the pitch of these blades through a manually controlled hydraulic system. By operating free of lubricants, pollution in the circuit is avoided. Axial thrust is counterbalanced partly by a regulated hydraulic pressure acting on a collet carried by the driving shaft and partly by a pressure-lubricated mechanical thrust-block.

Absolute tightness against leaks, both during operation and at shutdown, is achieved by the use of barrier fluids—CO_2 and oil—working at pressures adjustable from between 14 and 363 lbf/in², according to pressure variations upstream from the blower. To ensure leak-tightness on shutdown, the blower wheel is moved back by hydraulic control on to a special seating without the need to disconnect the blower-motor coupling.

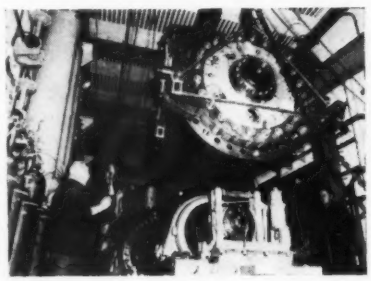
The test-loop consists of a steel tube with an inner diameter of 31 in. Its upper part, a straight length six times the diameter, carries in its centre a mass flow measuring instrument. Upstream of this device is a finned elbow unit that stabilises flow and detects its variations. A similar unit joins the top of the loop to the input side of the blower. Differential expansion in the loop is taken up by a 'Sepi' compensated joint; constant operating temperature is attained by the use of an oil and water jacket.

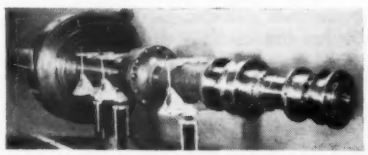
Examination of wear in the bearings, the hydraulic linkage and the leak-proof equipment is made easy by dismantling the rotor and bearings box without the need for depressurising the circuit (Fig. 4).

★ 280



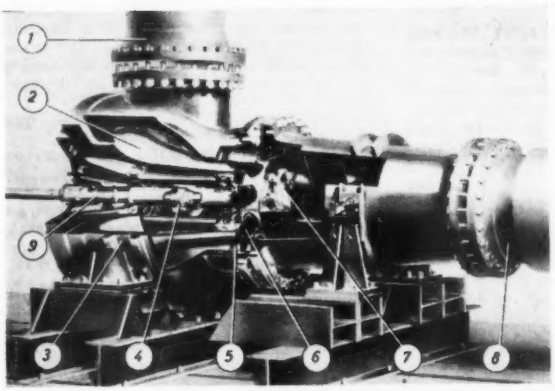
THE CO_2 blower and loop assembly is being tested for static seal tightness (Fig. 2)





▲ The rotor unit showing the three variable pitch fans (Fig. 3)

◀ Parts of the blower can easily be dismantled for inspection. Here the removable unit is being mounted in the stator elbow (Fig. 4)



◀ The experimental variable pitch blower designed by SNECMA for possible use in future EDF nuclear power stations (Fig. 1)

1 inlet duct
2 inner lining
3 outer casing
4 variable pitch servo-control
5 inlet guide blades
6 variable pitch blades
7 pitch setting control
8 exhaust duct
9 variable pitch rotor

Radiations effect

NBS calculation method

For problems involving rectangular sources of radiation such as shielding, food irradiation and photometry, the National Bureau of Standards has developed a series-expansion method of calculation. The method uses information on the angular distribution of radiation emerging from the surface of the source in the form of coefficients of a Legendre expansion and determines the detector response as a sum of products of these coefficients and other coefficients characteristic of a particular source rectangle. The resulting sum is accurate provided that either source angular distribution or source rectangle can be described by only a small number of coefficients.

For other cases, alternative sums are used that represent angular distribution of the source as a secant power series. A similar investigation is now in progress with the object of calculating the radiation which an off-axis detector receives from a circular disk source, e.g. the neutron flux around the face of a cylindrical thermal column of a research reactor.

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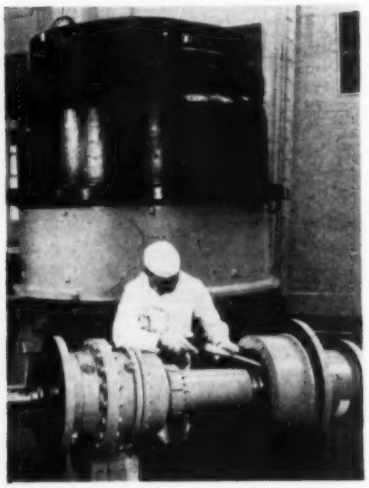
Gas circulators

design for Hunterston

Each of the eight CO_2 circulators being built by GEC for Hunterston's first reactor has a capacity of 710 lb/s and is driven by a 1230 V, 2354 hp double-armature d.c. motor running at 1050 rev/min.

The circulator components include a hollow impeller shaft, an impeller and dome casing. On one end of the shaft is a Crane gas seal assembly, specially developed to minimise coolant leakage at the point where the shaft penetrates the pressure shell of the steam-raising unit. The seal is supplied with oil, automatically maintained at 10 lbf/in² lower than the pressure of the circulating CO_2. When operating, gas leakage through the seal is $<0{\cdot}03$ lb/h and this is directed to the seal oil tank which is fitted with a stack to allow the gas to escape to the atmosphere.



Working in nuclear clean conditions, the operator is cleaning the thrust bearing carrying the hollow impeller shaft. The impeller, awaiting assembly, is seen on top of the dome casing behind

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Automatic pyrometer

high operating range

An automatic pyrometer which continuously measures and regulates up to 4000° C, while recording changes of <1°, has been developed by Atomics International. With attachments, it is claimed that the device is capable of operating up to 10,000° C.

About the size of a 16 mm cine camera the pyrometer, which is mounted on a tripod facing the heat source, operates on the basic measurement principle of sensitivity to light. A light bulb inside the unit adjusts to the brightness of the heat source, and the means of measurement is provided by

Originally developed by AI for high temperature materials research, this automatic pyrometer, capable of continuously measuring and controlling temperatures up to 10,000°C, is being calibrated against a standard lamp

an electrical current through the bulb. Temperature regulation is effected by a servomechanism connected to the power supply for the heat source and to a detector sensitive to the brightness of the bulb. This detector adjusts the signals from the heat source and the light-bulb until they have reached the same level.

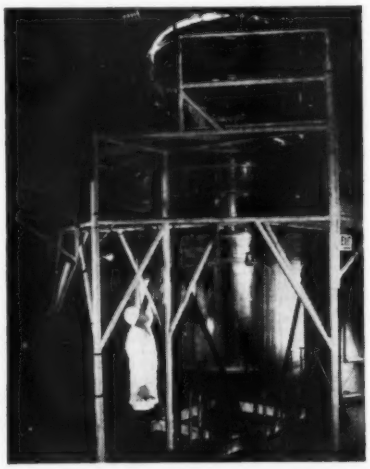
★ 283

HTGR simulator

gas flow studies

General Dynamics are using a transparent half-size scale model of the High Temperature Gas-cooled Reactor to simulate the gas flow conditions of the full-size 40 MW prototype reactor plant to be built at Peach Bottom, Pennsylvania. This model duplicates in every detail the internal helium coolant flow paths and includes half-size dummy aluminium fuel elements. The five-ton model is built of four concentric plexiglass shells that simulate the shields in the actual HTGR.

Through manometers connected to the model at every significant point in the gas flow path, and with the aid of numerous patch thermocouples, calculated flow rates and flow paths can be verified, and variations from the calculations can be corrected. Heat-transfer rates can also be investigated. By adding smoke to the incoming air, the gas flow through the transparent walls of the vessel can be visually observed.



This half-size scale model of the 40MW HTGR at Peach Bottom is used by General Dynamics to simulate every conceivable situation. Flow rates, pressures and flow paths can be changed easily

★ 284

IN BRIEF

NEW RESEARCH FACILITY IBM are to have a new research laboratory at Zurich. Work will be concerned mainly with the application of hydraulic mechanisms to logical devices, the physics and application of thin magnetic films and experimental aspects of semi-conductor materials.

★ 285

TOXIC GAS MEASUREMENT Tracerlab has received from the Wright Patterson Air Force Base a contract for the development of portable, super-sensitive instruments which will detect toxic gases at rocket fuel fabrication sites. They will investigate the feasibility of using clathrate and radiometric exchange techniques.

★ 286

NEW MAGNESIUM ALLOY. AEI has developed a new Magnesium alloy 'Magzan 2' which has sufficient strength to bear loads at 500°C, only 150° lower than the melting point of magnesium.

★ 287

EMERGENCY POWER SUPPLY. A simplified engine starting device for emergency generators has been patented by the UKAEA, Risley. In use at Dounreay and at Windscale, the device consists mainly of a single valve controlling the admission of compressed air to the engine. Normally in the closed position, the valve is opened by a falling weight, which, until an electrical power failure occurs, is held suspended by an energized solenoid. When the engine has started, the pressure of oil in its main lubricating system shuts the valve and at the same time latches the operating weight in the original position ready for the next start.

★ 288

NEW CARBON ISOTOPE A new carbon isotope of mass 16 has been discovered by the UKAWRE in collaboration with the Clarendon Laboratory. A carbon-14 target was bombarded with a beam of 6 MeV tritons from a Van de Graaff accelerator. The new isotope has a half-life of only 0.74s.

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★ *For further information on any item, circle the appropriate number on the reply card facing page* 106.

Points from Papers

reports, meetings, conferences

POWER MEASUREMENTS

One of the problems of capsule irradiation experiments is the apparent difference in sample power calculated by thermodynamic methods and that calculated by nuclear methods. A solution developed at GE–ANPD deals with irradiation of fueled samples in the HT–1 facility of the Materials Testing Reactor. The apparent difference was caused by the value of the neutron flux used to calculate the sample power. This value was determined at the beginning of the reactor cycle before any control rod movements are made. In addition the detector has a different response to neutrons in the irradiation hole to that of uranium, and the detector being placed on the outside of the sample cannot take into account the depression of flux within the sample. The report concludes that power determinations by the different methods agree within experimental limits and that flux wire data is adequate to determine sample power though variations in flux level due to sample geometry and reactor cycling need to be taken into account.

Correlations of power measured by thermodynamic and radiochemical analysis with flux wire measurements. G. A. Englesson and W. E. Niemuth. General Aircraft, Aircraft Nuclear Propulsion Department. 10 pp. Copies available from *Nuclear Power*.

ANALYSIS OF HGTC LOOP EXPERIMENTS

The problem is to find out the extent of fission product movements round the loop by analysing selected components. The remote handling techniques developed for this programme have a wide potential application and are described in detail. The chemical separations use slightly modified standard methods.

Remote-handling and analytical techniques used in the processing of samples from HTGC loop irradiations. P. E. Brown, R. H. Flowers and D. F. M. Lupton. AERE Harwell. **Report AERE R 3252.** Available from HMSO *5s.*

THERMOCOUPLE RESEARCH

The results of the thermocouple research programme established jointly by the Oak Ridge National Laboratory and the University of Tennessee are presented in this extensive report. The basic studies were concerned with the reliability of Chromel–P, Alumel thermocouples for measuring temperatures up to 1000°C, why this combination is good or bad, and is there a better combination. These basic studies have been extended and in addition research into the fundamental cause-effect relations of thermocouple behaviour has been carried out. The report includes detailed studies on the consistency of temperature measurement standards from 0–960°C; the oxidation of commercial and special thermoelements and the accompanying calibration changes; the physical properties such as cold-working, recovery and recrystallization, and their effects on calibration; and the specific performance of commercial thermocouples as influenced by time and temperature of operation.

Thermocouple research to 1000°C—Final report November 1, 1957 through June 30, 1959. J. F. Potts, Jr. and D. L. McElroy. Oak Ridge National Laboratory. **Report ORNL-2773.** 158 pp. Available from OTS $2·75 or depository library.

JOINT COMMITTEE REPORTS

The first report deals with information requested by the Congressional Joint Committee on Atomic Energy as a background for considering the authorization requested for the proposed Stanford linear accelerator project. Since the initial authorization request there have been considerable savings due to improved engineering and design data, and mainly by the adoption of the 'cut and cover' method of construction rather than the tunnelling originally proposed.

The second publication is not strictly a Committee report though prepared by the Committee staff. It contains no specific legislative recommendations but provides unclassified information of economic feasibility reports of generating by-product electricity with the new production reactor (NPR), a military plutonium producer, now under construction at Hanford.

Background information on the high energy physics program and proposed Stanford linear electron accelerator project. Report to Joint Committee on Atomic Energy. 445 pp. Available from US Government Printing Office, Washington 25, D.C.

Power conversion studies Hanford new production reactor. Joint Committee on Atomic Energy. 375 pp. Available from US Government Printing Office, Washington 25, D.C.

STABILITY OF ORGANIC MODERATORS

It is important to know whether the decomposition rates of Santowax R found by static tests are applicable to the same substance flowing in metal pipes. The growth of high boiler residue concentration for a period of 3000 h has been followed in tests carried out in the BEPO Mark 1 loop. The total thermal neutron dose was obtained from cobalt monitors and this was then related to the radiation energy input using previous calorimetric measurements. The difference between the static and dynamic results was of the order of 13% and this was thought to be due to the differences in the neutron energy spectra in the two cases. The authors consider that the static results obtained in silica capsules are thus applicable to flow in metal pipes.

The radiation and thermal stability of some potential organic moderator—coolants. Part iv; chemical determinations on the mark 1 organic loop in BEPO. T. H. Bates, W. G. Burns, R. F. Cumberland and C. R. Reed. AERE Harwell. **Report R 3564.** 12 pp. Available from HMSO *2s. 6d.*

IMPROVED AMPLIFIERS

A method is described of speeding up the response of feedback-type current amplifiers used with ion chambers. It involves the cancellation of the capacitance-charging currents which flow in the input circuit when the input current changes, thus eliminating the associated time constant.

Improving the dynamic behaviour of ion-chamber current amplifiers. C. E. Cohn. Argonne National Laboratory, Argonne, Illinois, USA. For copies apply to the author.

LIQUID SCINTILLATION COUNTING

A simple liquid scintillation counter uses a scintillator coupled to single photomultiplier tube. By using two photomultipliers in a coincidence circuit it is possible to eliminate unwanted pulses from thermal noise in the phototubes and phosphorescence in the liquid containing vessel. The apparatus described here incorporates further pulse amplitude discriminators and gating circuits so that only pulses falling within a desired energy band are recorded.

The identification of beta-emitting isotopes by liquid scintillation counting. W. P. Hutchinson. AERE Harwell. **Report AERE R 3605.** 9 pp. Available from HMSO *2s. 6d.*

SOLIDIFICATION OF WASTES

High activity liquid wastes can be converted to solids for permanent disposal using the pot calcination method. The wastes are evaporated to dryness and calcined in a portable stainless steel pot at 900°C. The pot is used as the final storage container. The off-gases are processed by evaporation, absorption and fractionation. The process has been developed for dealing with the first cycle raffinates from multipurpose fuel reprocessing plants.

Solidification of radioactive liquid waste by pot calcination. C. W. Hancher, *et al.* Oak Ridge National Laboratory. **Report ORNL-60-8-89.** 17 pp. Paper presented to the Winter Meeting of the ANS December, 1960. Copies available from *Nuclear Power*.

New Reports

Determination of thermal utilization of a lattice by a method of images; a semi-empirical method. Leo Seren and Lun Han Tang. Argonne National Laboratory. 2 pp. Copies available from *Nuclear Power*.

Fast neutron and gamma dose rate measurements about the heat transfer reactor experiment-III mockup. E. H. Brooks. General Electric, Aircraft Nuclear Propulsion Department. 9 pp. Copies available from *Nuclear Power*.

New Product Survey

EQUIPMENT · INSTRUMENTS · MATERIALS

PULSE ANALYSIS

non-overload amplifier

New from Hamner Electronics is the N-328 amplifier and combined pulse-height analyser which features ultra-high

The Hammer N-328 unit combines an amplifier and a pulse-height analyser. Front panel adjustments include two 10-turn helipots for the control of baseline and window width, and a switch for integral or differential operation

speed, non-overload characteristics together with optional pick-off for 40 mμs range coincidence.

The new unit has a gain of 7000, double delay-line pulse shaping and a choice of integral or differential discriminators. Resolving time is ~1·3 μs, and the output pulse has a width of ~1·0 μs and a rise time of 0·5 μs.

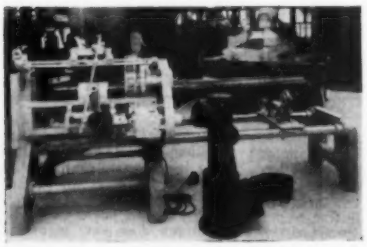
The amplifier is suitable for use where very large overload signals are present, such as those from large scintillation phosphors, where counting rates up to 250,000 counts/s are met, and where it is required to do coincidence work in the 50 mμs range with sodium iodide.

★ 208

TUBE PROFILING

versatile template machine

The new Hancock tube profiling machine makes its own templates and can deal with the weld preparation of pipes with diameters of from 3in to 12in. The standard machine prepares branches, and an optional attachment is available for cutting the corresponding holes in the main pipe. The pipes may be set either at right angles to each other or at any other angle of off-take.



Hancock's tube profiling machine is self-contained and easily transportable

The machine works from templates made direct from drawings by means of a special attachment. These templates may be made from stock pipe and drawings are available to cover a complete range of standard pipe sizes and angles; a library of standard template drawings is supplied with the machine. A multiplying device is provided that allows, for example, the template for a 3in pipe at 45° into a 6in pipe to be used for a 6in into a 12in pipe at the same angle.

★ 209

PULSE HEIGHT ANALYSER

transistorized unit

A transistorized, portable 400-channel pulse height analyser, occupying just one cubic foot and weighing about 30lbs, has been introduced by the Technical Measurement Corporation. The Model 404 uses a magnetic core memory system with data stored in parallel binary-coded-decimal form. Data can be read out directly from the memory into a printed device without auxiliary equipment.

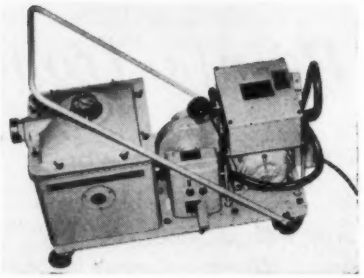
The new model accommodates four detectors at the same time and stores four separate spectra. Each input has its own amplifier and associated gain control. Pulse amplitude spectrum is displayed on a built-in cathode ray oscilloscope. Data may be read out through a high speed paper tape printer or punch, an IBM computor typewriter, an *X-Y* recorder, or a strip-chart type recorder.

★ 210

AIR FILTRATION

portable AGR unit

The Cimex absolute filter machine used for vacuum sweeping has now been adapted to form a portable ventilating unit suitable for radioactive air filtration. It is a two-stage filter with a ½hp 50c blower driving a fan at 11,000 rev/min. The first filter separates dust down to 4 microns into a disposable container; the second filter, a fabric one, has an area of 40ft² and ensures filtration down to 0·02 microns.



This portable ventilation unit, specially adapted for use in the AGR building, is a development of the Cimex radiation dust collector

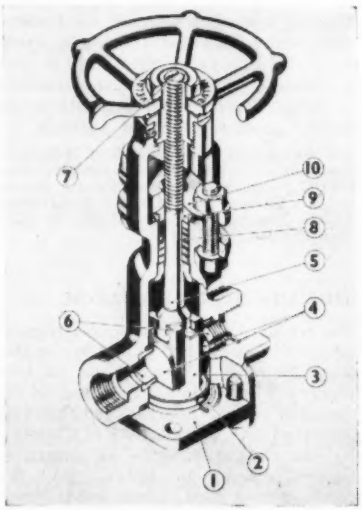
An adaptation of this unit has been made for use in the containment vessels housing the AGR gas loops at Windscale whenever personnel access is required. Air is extracted through 50ft of 1½in hose at the rate of 100ft³/min, and is filtered through a 0·2 micron size filter before recirculation into the containment vessel. This machine uses a fan larger than the standard and it is driven by a ¼hp motor at 8,000 rev/min. As the dust level in this application is lower than normal the coarse filter is not required and use is made only of a single absolute filter chamber.

★ 211

BONNETLESS VALVES

in-line servicing

Gate and globe types of forged steel, bonnetless valves which can be tested and fully serviced while still 'in-line' are being made by Newman Hender. They are available with flanged, screwed



The 'Newman-Velan' gate valve is suitable up to 600 lbf/in² at 482°C.
1 base 2 SS/asbestos gaskets 3 guide ribs
4 wedge 5 stem 6 seat rings 7 slot
8 packing 9 gland 10 yoke

or welded ends and can be made from stainless steel or other materials if required.

The gate valves which are available in standard bore sizes from ½in-2in are suitable for working pressures up to 600lbf/in². The globe type, in vertical or oblique patterns, are available in sizes from ¼in-3in and are designed primarily for extreme temperatures and pressures up to 2500lbf/in² at 593°C.

The base of the gate valve is formed by a bolted service cover sealed to the body by a gasket. The guide ribs which control the movement of the wedge are integral with the cover and facilitate removal and cleaning without the necessity for changing the body.

The centre of the service cover carries a screwed test plug. Removal of the plug provides a quick visual check for leakage and permits draining, flushing or cleaning out. During shut down, with the valve closed and plug removed, compressed air can be applied to check the valve for tightness with the valve 'in-line'. Removal of the complete service cover also permits the easy removal and replacement of the stem, wedges and seat rings; the entire operation can be carried out without disturbing the packing, gland or yoke.

The replaceable SS back seat is hardened, ground and lapped to provide positive isolation of the stuffing box from line pressure. The box is easily accessible and can be repacked safely and quickly with the valve in use.

The globe type valves can be supplied as stop, stop-check, needle or flow control valves and by complete interchangeability of parts it is necessary only to change the stem and disc to convert one type to another. The seat and disc, which are heavily stellited to resist wear and corrosion, can be relapped with the valve 'in-line' and a screwed plug in the base provides access for this operation.

★ 212

FLOW CONTROL

electro-mechanical valve

An electro-mechanical stop valve which can also be used to regulate the flow of fluids has been introduced by I.V. Pressure Controllers. Varying in size from 3in dia to 10in dia, the valve has a maximum working pressure of 550 lbf/in²g and it can also be manually operated by an override mechanism. The motor is reversible, has a maximum torque of 170lbf/in and requires a starting current of up to 4A.

The valve opens and closes according to the direction of rotation of a screwed spindle which is operated by an actuator geared to a shaft speed of 24 rev/min. Motivated by this actuator, the spindle engages a split nut and opens and closes the valve as it moves upwards or downwards. The speed of opening is 1in travel in 15s at a constant 400V.

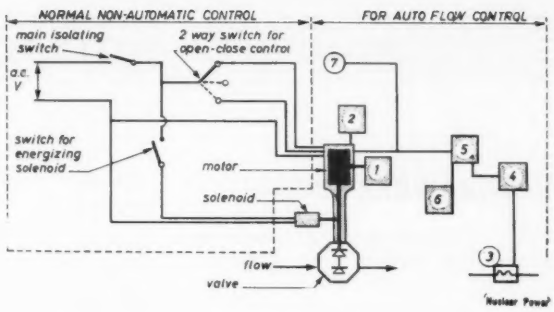
Fully open and closed positions are limited by micro-switches actuated by a flange on the spindle shaft. The split nut is held in engagement with the screwed spindle by a continuously rated solenoid energized by the electrical supply to a maximum stroke of 1½in. The solenoid is in series with the motor and, when energized, brings about the 'shut-down' in 0·1s.

As a flow regulating valve, a position indicator is employed to give electrical signals which can be translated into fluid flow. These signals are returned to the actuator and can open or close the valve from any intermediate position.

★ 213

I.V. Pressure Controllers' new electro - mechanical valve can be used for regulating fluid flow. A solenoid gives a shut-down period of 0·1s

1 valve position indicator 2 tachometer 3 flow counter 4 gates 5 amplifier 6 oscillator 7 normal control override



IN BRIEF

• **Welding torch.** The 350A 'Tec' spot gun introduced recently by Interlas, is a water-cooled portable tool which will spot weld stainless steel, mild steel, nickel alloys and other metals up to ⅛ in thick.

★ 214

• **High pressure air pump.** New in the Madan range of airhydropumps is a reciprocating type for component testing that produces pressures up to 100,000 lbf/in² from compressed air at 80/100 lbf/in². Pressure is fully controllable from 10,000 upwards.

★ 215

• **Data processing.** Panellit has introduced a fully encapsulated version of the 'Minilog' solid state transistorized logic system for industrial sequencing and control applications. One of the elements available has six inputs and drives up to five outputs; the other incorporates an emitter-follower and can drive up to 25 inputs.

★ 216

• **Automatic machining.** Using AEI's punched card setting system, the new Kearns 451P electronic planer table is very versatile and may be used for horizontal surfacing, boring, milling, drilling and tapping. It features a combined travelling spindle and facing chuck, each of which has a wide range of speeds for use either in combination or separately.

★ 217

• **High purity mercury.** Johnson Matthey are now able to supply for laboratory and industrial use mercury with a maximum impurity content of either 5 or 1 ppm.

★ 218

• **Spectrophotometer power supply.** A new transistorized type 115D unit, has been designed by Labgear to supply 6V d.c. voltage to their SP500 spectrophotometer. Stability factor is >1000:1, with ripple and noise at ≃3mV peak to peak.

★ 219

• **Transistorized amplifier.** The Hewlett-Packard 466A instrument, designed to increase the sensitivities of oscilloscopes or voltmeters, has a response flat within 0·5dB for 10c/s to 1Mc/s, with 3dB points at 5c/s and 2Mc/s.

★ 220

• **Analogue computer.** The TR-5 mounting unit offered by Electronic Associates makes it possible for special purpose analogue computers to be easily assembled. It contains all the controls necessary to operate a 20-amplifier computer.

★ 221

• **Electronic timer.** The N804 Hamner glow tube unit, a preset and elapsed electronic timer with a 60c controlled time base and a maximum time storage of 10,000s, may be used with any electronically gated scaler as well as other scalers that are stopped and started with mechanical contact closures.

★ 222

• **Industrial television tube.** Mullard's MW 13-38 new high brightness 5 in dia. projection tube has a light output of 970mk/cm² at an anode voltage of 50kV. With a raster size of 72 × 96mm, displays of up to 12·5 ft high can be shown.

★ 223

• **Stabilized power supply.** Allied Electronics' latest portable stabilized power supply unit, the EV451-A, provides fixed and variable d.c. outputs of 200 V and 0-300 V respectively. The internal resistance of the supply is $<0{\cdot}25\Omega$ and the impedance $<2\Omega$ up to 50 kc/s.

★ 224

• **Water-cooled triode.** For accelerators and other types of service requiring high peak power output, RCA have introduced a new ceramic-metal super-power triode—the RCA 7835. With a duty factor of 0·01 and a pulse duration of 25μs, it should provide up to 10 MW at 60,000 V peak.

★ 225

★ *For further information on any item, circle the appropriate number on the reply card facing page* 106.

STUDENTS' NOTEBOOK

GROUNDWORK—Materials

What is the importance of plutonium in the future development of nuclear power?

The bulk of natural uranium—99·3%—consists of U-238 which, whilst it is not itself fissionable to any great extent, produces the fertile isotope Pu-239 after nuclear reaction. The latter produces 16% more neutrons per fission than the fissionable U-235 which forms only 0·7% of the raw material and it has a relatively higher cross-section to fast neutrons. In the reactor, neutrons produced by the fission of U-235 are captured by the U-238 eventually leading to plutonium through the following reactions:

$$\text{U-238} \xrightarrow{n,\gamma} \text{U-239} \xrightarrow[23\cdot5\text{min}]{\beta-}$$

$$\text{Np-239} \xrightarrow[2\cdot33\text{d}]{\beta-} \text{Pu-239}$$

Whilst U-235 is used extensively at the moment, it is by nature scarce. Increasing effort is therefore being directed towards plutonium as an alternative fuel in the long range economic development of nuclear power. Possible fruitful lines of approach are discussed elsewhere in this issue by Dr M. B. Waldron of the UKAEA, Harwell.

Plutonium in the pure state, however, has poor physical, mechanical and thermal properties that make it an unsuitable solid fuel material. It has a relatively low melting point of 640°C and in the temperature range from room temperature to the melting point, plutonium has six allotropic forms and undergoes five solid state changes on heating and cooling. In some cases, these involve unusually large volume changes. The following indicates the percentage changes in volume from one phase to another, and the approximate temperature of transformation: alpha—→beta 8·9-11·3 (120°C), beta—→gamma 2·4-2·77 (208°C), gamma—→delta 6·7-6·8 (322°C), delta—→delta prime –0·1–0·4 (455°C), delta prime—→epsilon –3·0 (480°C), epsilon —→liquid ~0·1 (640°C).

To overcome these peculiarities, the fuel must be diluted with a non-fissionable material, e.g. either fertile isotopes such as U-238 or Th-232 or inert materials such as aluminium, molybdenum, etc. The properties of the fuel then take on those of the alloying element or diluent. Substituting a foreign atom for one of plutonium, however, effects the relative stability of one of the six phases and introduces changes in lattice parameter, electron average, and possible types of bonding. In addition, some elements favour one phase or the other because of atomic size.

There are many possibilities for the metallurgist to look at but the lines of development are conditioned by such factors as amenability to aqueous reprocessing techniques and the irradiation life of the fuel element. The systems most advanced at the moment include alloying with aluminium, resulting in a material resistant to high temperature water, and the plutonium-uranium-molybdenum system. The use of cermets such as PuO_2-UO_2 dispersed in a stainless steel or niobium matrix, and solid solutions of plutonium carbide in uranium carbide, show promising irradiation behaviour. Both bulk carbide fuel elements and the cermets present increased thermal conductivity resulting in low centre fuel temperatures for a given rating and thickness of element compared with the lower thermal conductivity bulk oxide.

FILMS

• *Transistors:* research and development, production methods and uses. 16mm, 25 min (in colour). Hire from Mullard Ltd, Torrington Place, London, W.C.1.

• *Nuclear power plant.* 16mm, 20 min (in colour). Free hire from The Nuclear Power Group, Radbroke Hall, Knutsford, Cheshire.

• *For mechanical advantage:* epicyclic gearing. 16mm, 25 min (in colour). Free hire from the Gear Sales Department, W. H. Allen Sons & Co. Ltd, Atlas Works, Pershore, Worcs.

• *Industrial applications of radioisotopes.* 16mm, 57 min (in colour). Free hire from the US Embassies in London, Brussels, Buenos Aires and Tokyo (USAEC).

A number of firms in the UK offer training facilities to Commonwealth students. The AEI (Rugby) Ltd for instance award scholarships to cover two years' training in engineering and experience in the Company's various departments and factories. Recent arrivals are the five Australians and three South Africans seen here looking at a model of a 400 hp circulator for the Berkeley nuclear power station

NEWS

• Under a recently granted ordnance for the establishment of a chair of nuclear engineering, Glasgow University will be able to go ahead with the new department, once the financial aspects are settled.

• South Africa's Southern Universities Nuclear Institute, being built on public subscription at the cost of £500,000, has been registered as a company. The Board consists of representatives of the Cape Town and Stellenbosch Universities, the Atomic Energy Board, the Council for Scientific and Industrial Research, the Cape Provincial Administration and private industry.

• The UKAEA recently invited qualified science teachers from schools in southern England to a five-day course at Harwell to supplement their existing knowledge of nuclear physics and atomic energy. A similar service, but for eight-weeks, is being given to American teachers from the smaller colleges by the Oak Ridge National Laboratory.

• To aid research in the field of atomic reactions in the upper atmosphere, the US Advanced Research Projects Agency has supplied Queen's University in Belfast with a £50,000 Deuce high-speed digital computer. A further £23,000 will be given over the next five years.

• A recent Harwell publication, AERE-M650 (HMSO–6s.), presents in a readily assimilative form sufficient transistor circuit theory and actual circuits to permit their immediate use in electronic experimental work. The publication is not intended as a basic grounding in the subject.

• During the present academic year, of the 18 DSIR Research Scholarships awarded to young post-doctoral research workers in the fields of science and technology, seven are for chemistry and seven for physics.

• For teaching metallurgy and for industrial laboratories, Metallurgical Services have produced a collection of annotated metallographic specimens arranged in small balanced sets, each consisting of the same class of material.

UK COURSES

South East London Technical College: Institution of Electrical Engineers—Part III examinations: 6 months' full-time course commencing October 16, Fee: £17; Electric Circuit and Field Theory, about 25 lectures each Tuesday evening commencing October 17, Fee: £1 10s.

Martonair Ltd, Richmond, Surrey Five-day course in Applied Pneumatics for designers and users of pneumatic equipment commencing October 2, Fee: £8 8s (without accommodation).

CASTROL INDUSTRIAL OILS

Castrol Industrial Oils chosen for Dungeness Nuclear Power Station

Sir Robert McAlpine & Sons Ltd., who are constructing Dungeness Nuclear Power Station, use Castrol Industrial Oils in all their equipment.

The Power Station is designed for a net output of 550 Mega watts and will be lubricated by Castrol Radiation Resistant as well as conventional lubricants.

Castrol INDUSTRIAL OILS

CASTROL INDUSTRIAL LIMITED, CASTROL HOUSE, MARYLEBONE ROAD, LONDON N.W.1.

BUSINESS NEWS

AEA ISSUES 1960 ACCOUNTS The net cost of **UKAEA** operations for the year ended March 31, 1960 was £58,600,000. Sir Edmund Compton, Comptroller and Auditor General, remarks that arrangements have been made for periodic comparisons of the amount spent on research and development in aid of the nuclear power programme with the amount recovered by means of royalties. The AEA balance sheet also shows that fixed assets were valued at £239,414,276 compared with £210,374,637 in 1959 and assets in the course of construction at £30,308,918 (£40,072,191). Work in progress was put at £131,932,565 worth against £113,612,697 in 1959 while loans and advances for the production of uranium amounted to £17,680,482 (£21,353,465 in 1959).

B & W LOSE ON NUCLEAR WORK Losses sustained by **Babcock & Wilcox Ltd** on work for the Hinkley Point and Trawsfynydd nuclear power stations in 1960 amounted to £650,000, Sir Kenneth Hague, the chairman, notes in his annual review. He adds that a provision of £700,000 out of the existing contingencies reserve has been made for further losses which may be incurred on these nuclear contracts before they are completed. The exacting requirements and unprecedented labour problems at site proved most expensive. Meanwhile, at the firm's works, all components for Hinkley and Trawsfynydd had been virtually completed and the company now had to find employment for the specialised plant until the new contract for the Sizewell station reached the shop floor towards the end of this year.

UK GAUGES FOR RUSSIA Eight transmission gamma ray thickness gauges to be installed in steel mills are to be supplied to the Soviet Union by **Davy and United Instruments Ltd,** Sheffield, under terms of a contract signed with **Stankoimport,** Moscow. The value of the contract exceeds £90,000 and delivery will take place in the first quarter of 1962. The radioactive source and detection device will be supplied by **Isotope Developments Ltd** of Reading.

RIO TINTO DIVERSIFIES The development of associations with a number of important industrial concerns in Europe and North America by **Rio Tinto** was commented upon by Mr Val Duncan, managing director in his annual report. He remarked that it was a good long term policy to extend the production of uranium beyond the crude oxide stage and the associations developed by Rio Tinto would, he thought, become increasingly important with the growth of nuclear power.

• Following an agreement with **P. R. Mallory and Co Inc,** the **Plessey Company Ltd** is now manufacturing a range of solid electrolyte tantalum capacitors.

• Prompt action by two security men checked the spread of a fire which broke out on Monday, May 22 at the **Hawker Siddeley Nuclear Power** plant at Langley, Bucks. The fire was not connected with the JASON reactor and was confined to one bay where it had started in a chemical plant.

• **Elliott-Automation Ltd** announce that for certain applications, joint marketing arrangements have been arranged between **The Rheostatic Co Ltd** and **Black Automatic Controls Ltd,** both member companies of the group.

• The computer department of **Ferranti Ltd** has established a permanent office in Melbourne.

• Additional factory premises in Wimbledon have have been acquired by the scientific instrument makers, **British Rototherm Co Ltd.**

OVERSEAS

GERMAN COMPANIES MERGE Three West German companies have agreed to merge their nuclear research divisions into a new company called **Igenieurgemeinschaft Kernvertahrentechnik Leybold-Lurgi-Uhde.** The three companies are **Leybold Hochvakuum Anlagen GmbH** (Koln), **Lurgi Gesellschaft fur Chemotechnik** (Frankfurt) and **Friedrich Uhde GmbH** (Dortmund). Reason for the merger is to consolidate development and planning. Main tasks will include the development and application of reprocessing plants and the handling of radioactive solid waste.

MARY KATHLEEN PROFITS UP An electronic sorting plant enabled **Mary Kathleen Uranium Ltd** to increase its production of uranium oxide by 140,000 lb last year. Oxide output was 1,475,851 lb and the company's profit rose from £A3,723,886 to £A3,889,756 in spite of a lower tonnage milled. The company lost more than 10% of operating time, mainly because of industrial difficulties.

SWEDES VISIT RUSSIA The Soviet organization **Glavatom** was host to a six man delegation from **AB Atomenergi** of Sweden who spent a fortnight in Moscow from June 6 studying industrial applications of atomic energy in the Soviet Union. The Swedish party was headed by AB Atomenergi's managing director, Mr Harry Brynielsson. A party from Glavatom, led by Professor V. S. Emelyanov, is expected to visit Sweden this summer.

• **Sumitomo Atomic Energy Industries,** Japan, plans to build a research laboratory with a water type critical assembly at Tokai-Mura.

• A gamma field in Ibaraki Prefecture has been completed by the **Japanese Agricultural Ministry.** It will be used to conduct research on improvement of plant strains. First experiments begin in July.

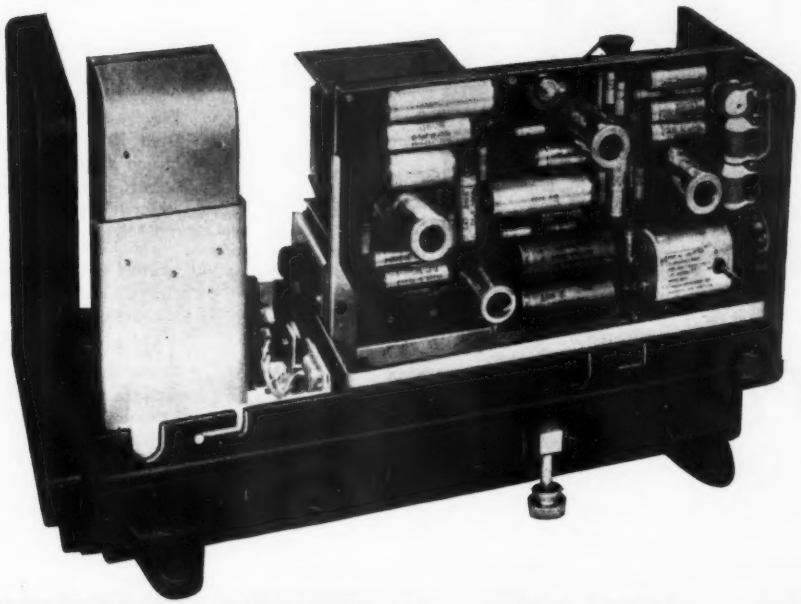
• **Westinghouse Atomic Fuel Division** has been awarded a contract to fabricate 1739 fuel elements for the Atomic Energy Commission's Experimental Gas-Cooled Reactor being built at Oak Ridge Tennessee.

• **Vitro Corporation** of America and **Selenia S.p.A,** a Raytheon Company subsidiary, have formed a new company in Italy—**Vitroselenia**—for the design and installation of missile systems and other electronic equipment.

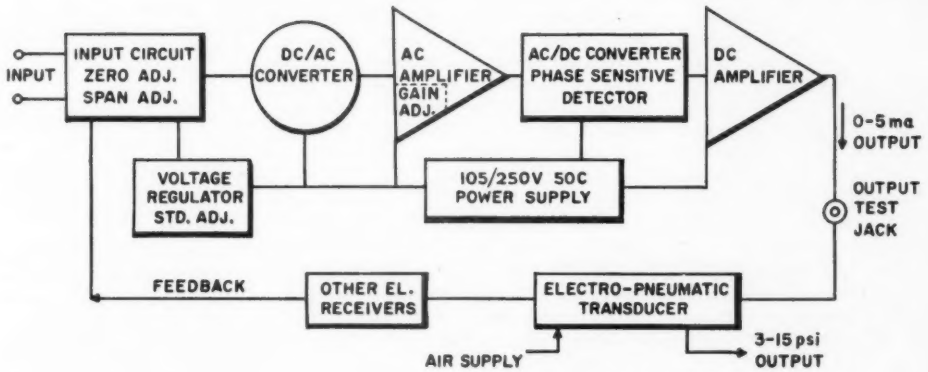
A view of the McFadzean Laboratory of British Insulated Callender's Cables which was officially opened by the Duke of Edinburgh in May. The laboratory exists to carry out long-range experimental work for the engineering laboratories which form part of every BICC production unit. The six storey building was built at a cost of about £500,000

Taylor POTENTIOMETER TRANSMITTER

represents a unique concept in a bridge balancing Potentiometer.



ELIMINATES NEED for Slide Wire—Battery—Standard Cell or Moving Parts



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A UK technical team visited the USA recently to obtain information on the EGCR, the American counterpart of the Advanced Gas Cooled Reactor. With AEA staff, led by Dr Gordon Brown of Reactor Group, was Mr K. P. Gibbs of the CEGB. They are seen in consultation at Oak Ridge with Dr D. F. Cope, Director of Reactor Division, AEC on the left and Mr Wilson Cooper, Tennessee Valley Authority on the right.

People

by John Radford

ONE OF Britain's leading metallurgists, **Professor B. E. Hopkins,** is to become the first Batelle Professor of Metallurgy at Ohio State University. He is at present senior principal scientific officer at the National Physical Laboratory, Teddington. Professor Hopkins is well known for studies resulting in a better understanding of metals designed to meet the extreme temperature requirements of the space age.

The English Electric/Babcock & Wilcox/Taylor Woodrow atomic power group have appointed 39 year old **Mr J. H. Thornton** as the Group Resident Superintendent for the 580 MW Sizewell station. Mr Thornton was chief civil engineer in the Group Resident Superintendent's department at the Hinkley Point station and until February 1 this year, was assistant Group Resident Superintendent. From 1946 to 1957, he was senior engineer and resident engineer with Sir William Halcrow and Partners on the design and construction of hydro-electric projects for the North of Scotland Hydro-Electric Board.

An Imperial College of Science engineering graduate, **Harold Etherington,** is now general manager of the Allis-Chalmers Atomic Energy Division. His associations with Allis-Chalmers started in 1937 when he was an assistant engineer in the engine and condenser department. Since then, he has been active in the field of atomic development. Early in World War II, he was working on special engineering for the Manhattan project and in 1946 was given leave of absence to join the Power Pile division at Oak Ridge National Laboratory and was later director of the Naval Reactor Division responsible for the basic nuclear engineering design of the nuclear powered submarine, *Nautilus*.

Cooper Electroheat Ltd, a Southport company specializing in electrical preheating and stress relieving, have appointed **Mr D. R. T. Kidd** to their staff. He was formerly with the Transformer Division of English Electric and for a short time was with their Export Department in London.

A new face at E. G. Irwin & Partners Ltd is that of **Mr E. W. Herrington** who has been appointed engineer in charge of the Mechanical and Electrical Service Department of the firm's Industrial Division. Before moving to Irwin's, one of Europe's largest design, development and consulting engineers, Mr Herrington was with the Turiff Construction Co. Ltd where he was chief development engineer. Previously with the Ministry of Works, from 1925-58, Mr Herrington was concerned then with the development and construction of the principal atomic research establishments.

The Danish physicist, **Niels Bohr,** who recently visited the Soviet Union, has been elected Professor Emeritus of Moscow University.

Mr F. J. B. Barry, who was closely connected with the inquiry into some sections of the electrical industry by the Monopoly Commission, is the new commercial manager of the GEC's engineering works at Witton, Birmingham. A Hampshire man, Mr Barry joined the GEC in 1955 as manager of the plant liaison department in London after service with Metropolitan-Vickers Electrical Company broken only by a period in the Ministry of Supply as deputy director of weapon production.

Project engineer for the preliminary design of the organic moderated and cooled reactor for Baden Wurttemberg Nuclear Power Plant Planning Association (KBWP) of Germany is **Edward F. Weisner** of Atomics International, the firm designing the reactor section of the 150 MW plant. Mr Weisner was formerly project engineer for the AI Piqua 11.4 MW plant and has been closely associated with that project since late 1955. His successor at Piqua is **Jack Jacobson,** who was formerly in charge of the process system for the Piqua plant.

Manager of the newly formed high power klystron division of the English Electric Valve Co Ltd is **Mr M. Esterson.**

Messrs. **A. D. Howie, N. L. Honour** and **A. W. Knowlson** have been appointed to the board of W. J. Brooker Ltd.

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Sizewell Superintendent

HAROLD ETHERINGTON
General manager

D. R. T. KIDD
New appointment

E. W. HERRINGTON
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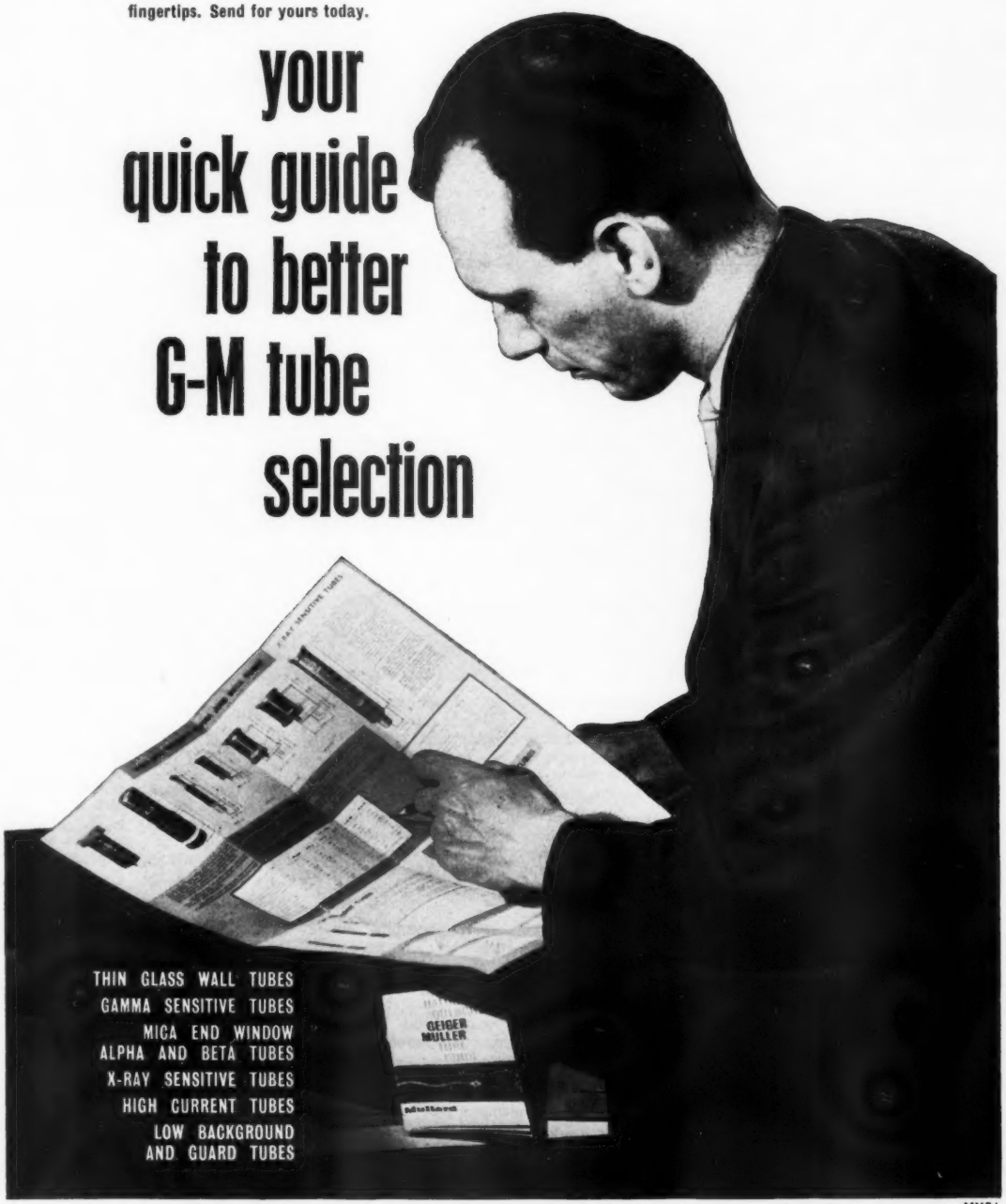

MXR1

Diary

21 JUNE—1 JULY
Sixth International **Plastics** exhibition and convention, Olympia, London

20—26 JUNE
Third **congress, European Federation of Chemical Engineering,** Olympia, London. Details, Institution of Chemical Engineers, 16 Belgrave Square, London, SW1

10—12 JULY
Thermoelectricity Conference, Durham. Details, Institute of Physics and the Physical Society, 47 Belgrave Square, London, SW1

10—14 JULY
Annual conference, **electron microscopy** group, at the University of Nottingham. Details, Institute of Physics and the Physical Society, 47 Belgrave Square, London, SW1

18—21 JULY
International symposium on **inorganic polymers,** University of Nottingham. Details, General Secretary, The Chemical Society, Burlington House, London, W1

OVERSEAS

23 JUNE—2 JULY
International exhibition including safety appliances and **radiation protection,** Cologne. Details, M. Neven DuMont, 123 Pall Mall, London, SW1

25—30 JUNE
Annual meeting, American Society for Testing Materials, including symposium on **radiation effects on refractory fuel compounds,** Atlantic City, N.J., USA. Details, ASTM, 1916 Race Street, Philadelphia 3, Pa., USA

26—28 JUNE
Commercial and Scientific Exhibition, Montreal, Canada

26—30 JUNE
Gordon Research Conference on **nuclear chemistry,** New London, Connecticut, USA. Details, W. G. Parks, Director, Gordon Research Conference, University of Rhode Island, Kingston, R.I., USA

Annual meeting, section on **radiology,** American Medical Association, New York, USA. Details, Dr Clyde A. Stevenson, Sacred Heart Hospital, West 101 8th Avenue, Spokane 4, Washington, USA

26 JUNE—1 JULY
International **measurements conference (IMEKO),** Budapest. Details, Professor J. F. Coates, Cambridge University, Trumpington Street, Cambridge or IMEKO Secretariat, Budapest 5, POB 3

9—14 JULY
International **Bio-Medical Electronics** Exhibition, New York, USA

16—22 JULY
Fourth international conference on **biomedical electronics** and 14th conference on electronic techniques in medicine and biology, New York, USA. Details, Dr Herman Schwan, University of Pennsylvania, School of Electrical Engineering, Philadelphia, Pa., USA

17—21 JULY
Gordon Research Conference on **radiation chemistry,** New Hampton, New Hampshire, USA. Details, W. G. Parks, Director, Gordon Research Conference, University of Rhode Island, Kingston, R.I., USA

24—28 JULY
Gordon Research Conference, **Corrosion and oxidation of metallic surfaces,** New London, New Hampshire, USA. Details, W. G. Parks, Director, Gordon Research Conference, University of Rhode Island, Kingston, R.I., USA

27 JULY—1 AUGUST
International symposium on **macromolecular chemistry,** Montreal, Canada. Details, Dr Rudolf Morf, c/o F. Hoffman Laroche S.A., Grenzachterstrasse 124, Basle, Switzerland

31 JULY—4 AUGUST
International Congress of Biophysics, including session on **radiation biophysics,** Stockholm, Sweden. Details, B. Londstrom, Karolinska Institutet, Stockholm 60, Sweden

31 JULY—12 AUGUST
Electric Power seminar, including sessions on **prospects and problems of nuclear power,** Mexico City, Mexico. Details, UN Economic Commission for Latin America, Avenue Providencia 871, Santiago, Chile

3—11 AUGUST
IAEA seminar on **the physics of fast and intermediate reactors,** Vienna

Future Months

SEPTEMBER (date later)
International symposium on **electron and neutron diffraction,** Kyoto, Japan. Details, Science Council of Japan, Ueno Park, Tokyo

17–19 OCTOBER
Fourth Japan conference on **radioisotopes,** Osaka City (postponed from May and venue changed). Details, Japan Atomic Industrial Forum, Inc. No. 1, 1-chome, Shiba Tamura-cho, Minato-ku, Tokyo

14–17 NOVEMBER
Symposium on **corrosion in nuclear technology,** Paris. Details, Association des Ingenieurs en Anti-Corrosion de France et l'Union Francaise, 28 rue Saint Dominique, Paris, 7e

6–8 DECEMBER
Symposium on **nuclear instrumentation,** North Carolina. Organized by American Institute of Electrical Engineers, Institute of Radio Engineers and Instrument Society of America

Industrial Literature

Metal heat-treatment. A recent issue of 'The Wild-Barfield Heat-Treatment Journal' contains an article on the use of controlled atmospheres in the heat-treatment of metals. ★ **246**

Nucleonic equipment. The complete range of Elliott Nucleonic's equipment, covering scalers, ratemeters, amplifiers and ancillary equipment, is detailed in a recently issued loose-leaf brochure. ★ **247**

Process control. The principles and operation of the 'Anatrol' on-line process control computer, recently described at the Brussels International Conference on Analogue Computation, are presented in de Havilland's publication 5115. ★ **248**

Aluminium alloys. The Imperial Aluminium Co supplies three grades of commercially pure aluminium: Impalco P3, P5 and P10, and a range of non-heat-treatable and heat-treatable alloys. Physical mechanical properties and other technical data are given in a recent Impalco catalogue. ★ **249**

Silicone applications. The principal uses of Midland Silicones MS4 compound, as described in a new leaflet are: the sealing of electric heating elements, corrosion prevention, the lubrication of mechanisms, and the reduction of hardening and cracking due to oxidation of natural and synthetic rubber and plastics. ★ **250**

Electromagnetic flowmeters. Fischer and Porter's latest manual on obstructionless flowmetering forms a comprehensive guide to basic principles and specifications. ★ **251**

Industrial plant. A recent prestige publication from T. W. Ward, introducing a variety of plant and equipment, deals with such installations as packaged boilers, pressure vessels, ducting and pipework. ★ **252**

pH meters. Electronic Instruments' current range of meters for pH measurement, featured in a recent brochure, cover types for use in laboratories, hospitals and industrial plants. ★ **253**

Radiation monitors. Specifications for E.M.I. Electronic's range of monitors and probes are given in a new short form catalogue. ★ **254**

Platinum metals. Among the varied industrial uses of platinum introduced in a new Engelhard publication are: thermocouples, resistance thermometers, electric furnace windings, electrical contacts and high-temperature brazing alloys. ★ **255**

Analogue computer. Electronic Associates' brochure on their 231R, 100 amplifier, general purpose computer, describes in detail the basic system, the building block design and a number of automatic features. ★ **256**

Thermocouples. Johnson Matthey's 'Noble metal thermocouples'—third edition—includes a summary of the behaviour of the many thermocouple combinations and recommended applications. ★ **257**

Liquid level control. Elcontrol's data sheet LR4 deals with the current range of conductivity type level controllers suitable both for conductive liquids and for free flowing solids having an adequate moisture content. ★ **258**

Glass drain-pipes. Bulletin PE-30 from Corning, on the Pyrex type 'double-tough' drain line, contains product and property data and lists the advantages of the system for the disposal of chemical wastes. ★ **259**

Welding and brazing. A new leaflet from Welding Improvement sets out the properties and application of the 'Fontargen' range of low heat input metal joining alloys. ★ **260**

German nuclear industry. A recent brochure from Allgemeine Elektricitäts - Gesellschaft (AEG) includes illustrated details of the Kahl nuclear power station, the Karlsruhe isochronous cyclotron, the modified Argonaut and some of the test facilities at the AEG laboratory at Grosswelzheim. ★ **261**

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WHY COULDN'T THEY PUT THEM SOMEWHERE ELSE?

Since Jim and Mary were here last, the transmission towers have appeared. Why couldn't they put them somewhere else? This couple will soon be back in town — switching on the light, the kettle, the oven. She'll do some ironing; he'll use his power drill; they will both watch T.V. The current they use may reach them along the power line they dislike. There were several possible paths for these towers. One wasn't just plotted on the map. Men stood here to judge the effect, to balance the needs of power with the natural lie of the land . . . men of the Central Electricity Generating Board, who, by Act of Parliament, are charged with a double duty: to provide an efficient and economical electricity supply and preserve as far as possible visual amenity.

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Book Reviews

Russian views on nuclear reactions

Russian scientists seem to have a gift for writing intelligible and didactically first-class books which are attractive even in a translation. Landau and Lifshitz's book on quantum mechanics is one case which has recently come to the notice of the reviewer; Professor Markow's book is another. Markow is a theoretician, but the book is written at the Dubna laboratory where the 600 MeV cyclotron and 10 BeV synchrotron are operating. The book contains a happy balance of experiment and theory, always illustrating the main issues by examples and plenty of text, as in the case of isotopic spin assignment, conservation of parity, strangeness, and the general systematics of mesons. The text is subdivided as follows: general characteristics of hyperons and mesons; isotopic spin and the systematics of the elementary particles; and interactions between fundamental particles; followed by tables on the threshold energies of the reactions involving nucleons and deuterons and mesons and gamma rays. Whilst most of the contents of this book are fairly well established, it seems that the section on the need for introducing an elementary length into the interaction between fundamental particles might have been placed in an appendix as an interesting ' theoretical experiment '.

Though the book was published in 1957, its translation into German was certainly worthwhile; an up-to-date English version would be valuable.

E. Bretscher

Hyperonen und K-Mesonen by M. A. Markow DeutscherVerlag der Wissenschaften, Berlin, 1960 328 pp Price DM42·80

Powder techniques for the nuclear chemist

The authors' objective ' to provide a conveniently small book setting out as simply as they can just those things which they think that an inorganic chemist who wishes to use X-ray powder techniques needs to know ' has been done most successfully. The authors' wide experience in the crystallography of radioactive materials, gained from their work at the UKAERE gives a certain bias making the book particularly useful to those who work in nuclear energy projects.

The first 61 pages are concerned with the apparatus and experimental details of powder techniques. The use of focusing cameras and monochromatic radiations, in order that useful information can be obtained even from imperfect materials, is emphasised. In the second part, a brief but complete treatment of the theory necessary for the interpretation of powder patterns is given in 95 pages. Methods for indexing, accurate measurement of unit cell dimensions and the determination of atom positions are illustrated with specific examples which make the general theory clearer to the non-specialist. There is useful advice also on the relative merits of the different methods. The remainder of the book is devoted to examples, many of which concern compounds of polonium and the actinides, that have been carefully chosen to illustrate the versatility of X-ray powder techniques. These provide ample proof of the authors' contention that powder photography is one of the basic techniques of modern inorganic chemistry.

J. A. W. Dalziel

X-ray powder photography in inorganic chemistry by R. W. M. D'Eye and E. Wait. Butterworths, London, 1960. 222 pp. Price 45s.

Recommended practices in radiation

The publication of a new section of the most recent Recommendations of the International Commission on Radiological Protection is always of interest to the health physicist, though it must be admitted that he generally has a fore-knowledge of its content. To those not actively engaged in the field, the title of the present publication is perhaps slightly misleading.

While there are 18 pages covering definitions and recommendations concerning installations using X-rays and sealed radioactive materials, both for medical and non-medical use, the appendix, running to 38 pages contains some very valuable tables and graphs. Apart from a group giving attenuation in concrete and lead for radiation from X-ray tubes operating at potentials from 50 kV to 3 MV, and from various radioisotopes, there are graphs giving transmission of scattered radiation through barriers, data which is less readily available. Tables giving skin and gonad doses per exposure, for various diagnostic examinations, are particularly valuable for assessing the total doses received by radiation workers from all sources.

It seems unnecessary to include the Report of the Main Commission yet again, since it has already appeared as a separate volume and in the Report of Committee II but, if it is essential, it should be placed at the beginning, not at the end, of the present volume. This, however, is a minor criticism of a book which should be in the library of any person concerned with the use of ionizing radiations.

H. D. Evans

Recommendations of the International Commission on Radiological Protection. Report of Committee III on Protection against X-rays up to energies of 3 MeV and beta-and gamma-rays from sealed sources. 1960, Pergamon Press. 84 pp. Price 21s.

New books

• *Protection against radiation* by J. D. Abbatt *et al.* Cassel, London 1961 235 pp Price 25s ★ **262**

• *Electromagnetic structure of nucleons* by S. D. Drell and F. Z. Zachariasen Oxford University Press 1961 111 pp Price 12s 6d ★ **263**

• *Theorie von Raum, Zeit und Gravitation* by V. Fock Akademie-Verlag, Berlin 1960 501 pp Price DM42.50 ★ **264**

• *Precision measurement and calibration.* National Bureau of Standards Handbook 77, 3 volumes, 1961. US Gvt. Printing Office (per HMSO). Vol. 1–Electricity and electronics, 845 pp, Price $6; vol. 2–Heat and mechanics, 965 pp, Price $6.75; vol. 3–Optics, metrology and radiation, 1025 pp, Price $7 ★ **265**

• *USSR Official Bulletin of Patents and Inventions* (cover to cover translation—fortnightly). *Derwent Japanese Patents Report* (commences May). Derwent Information Service, London. Both £40 subscription per annum ★ **266**

• *Encyclopaedia of engineering.* 100 volumes (to be published). State Scientific & Technical Press, USSR. ★ **267**

• *Applied thermodynamics* by S. H. Bransen. Van Nostrand, New York and London. 1961. 230 pp. Price 30s ★ **268**

• *British nuclear power stations* by R. Hammond. Macdonald, London, 1961. 182 pp. Price 25s ★ **269**

• *Basic principles of nuclear science and reactors*, by A. M. Jacobs *et al.* Van Nostrand, New York and London, 1960. 262 pp. Price 49s ★ **270**

• *Atomic energy waste: its nature, use and disposal*, edited by E. Glueckauf. Interscience, New York; Butterworths, London, 1961. 420 pp. Price 95s ★ **271**

• *Russian - English / English - Russian nuclear dictionary*, 2 volumes. Moscow (per Collet's, London). Price 40s ★ **272**

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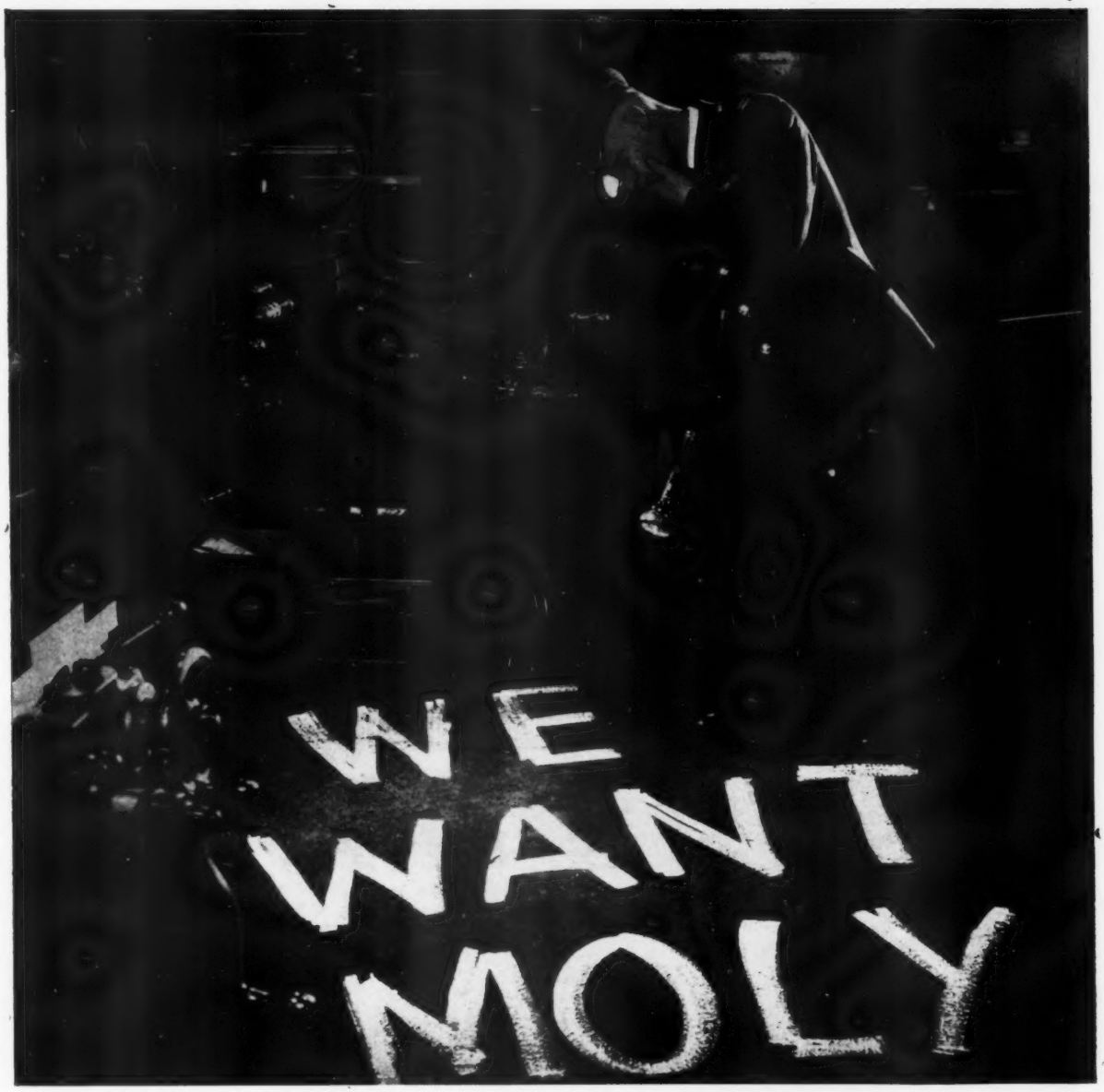

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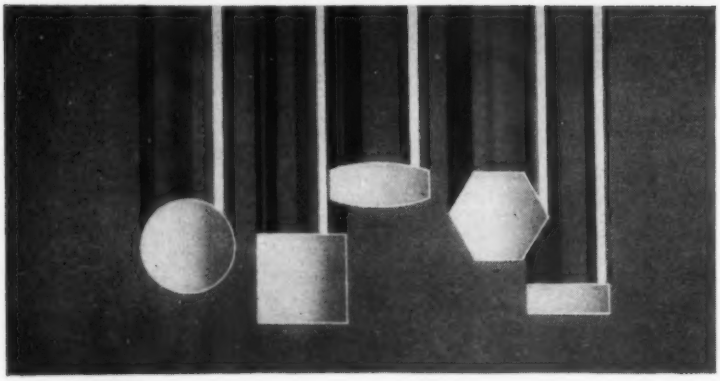

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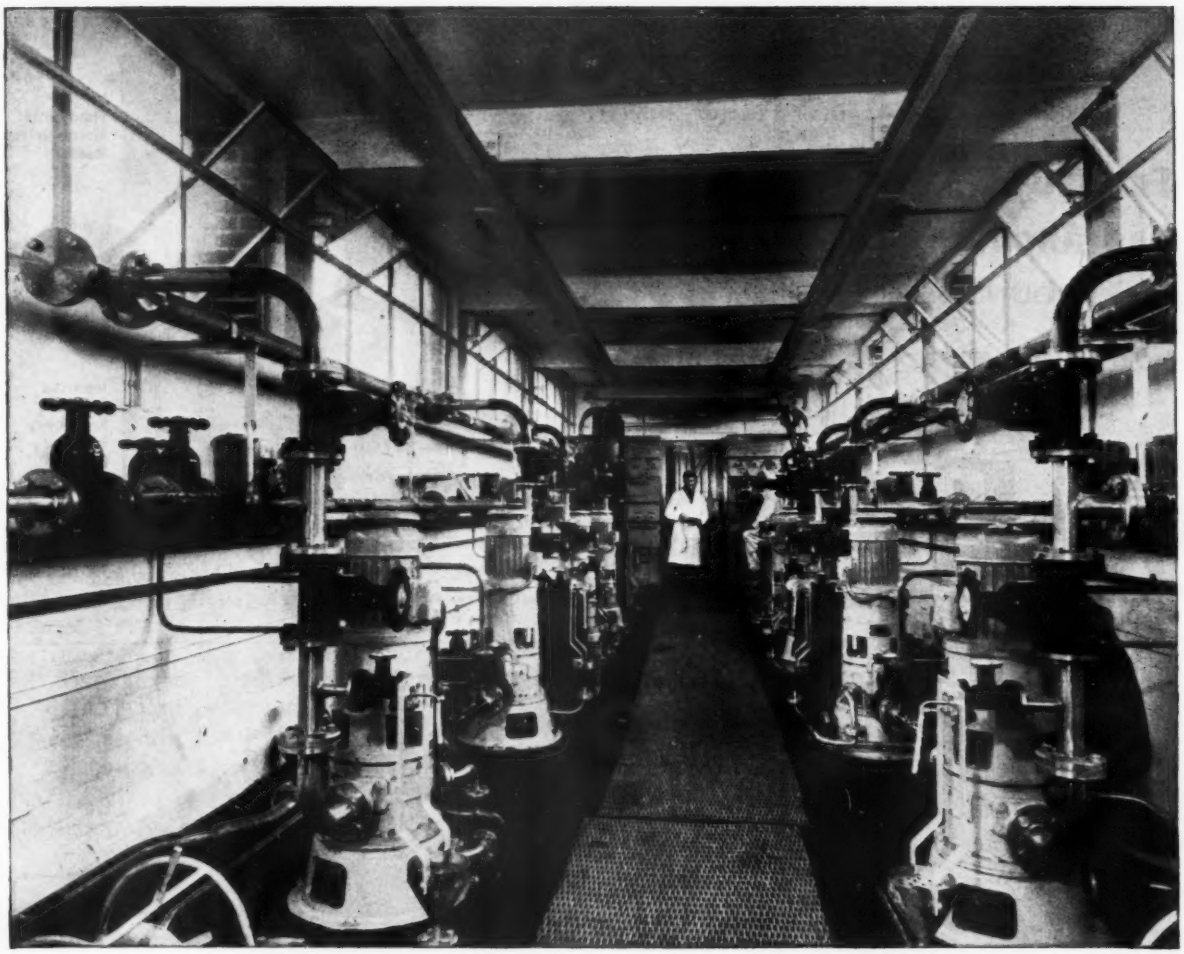

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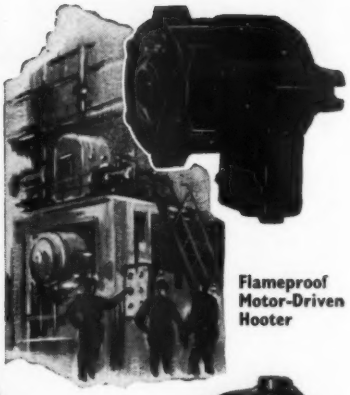

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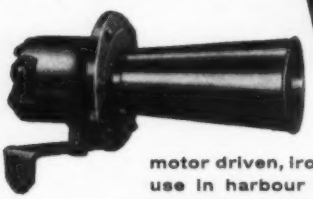

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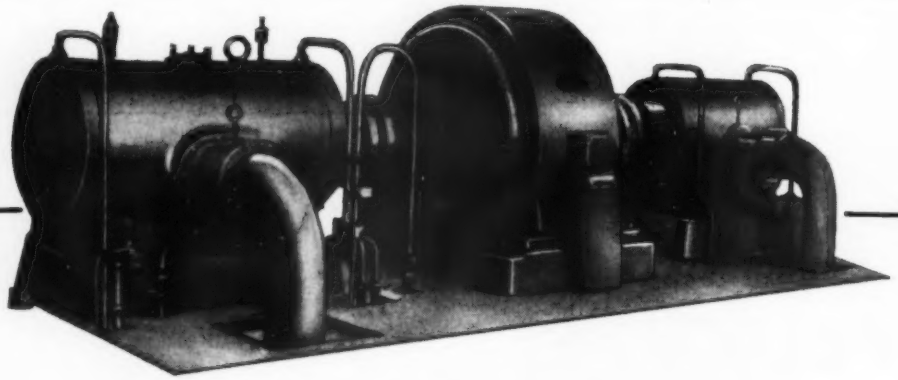

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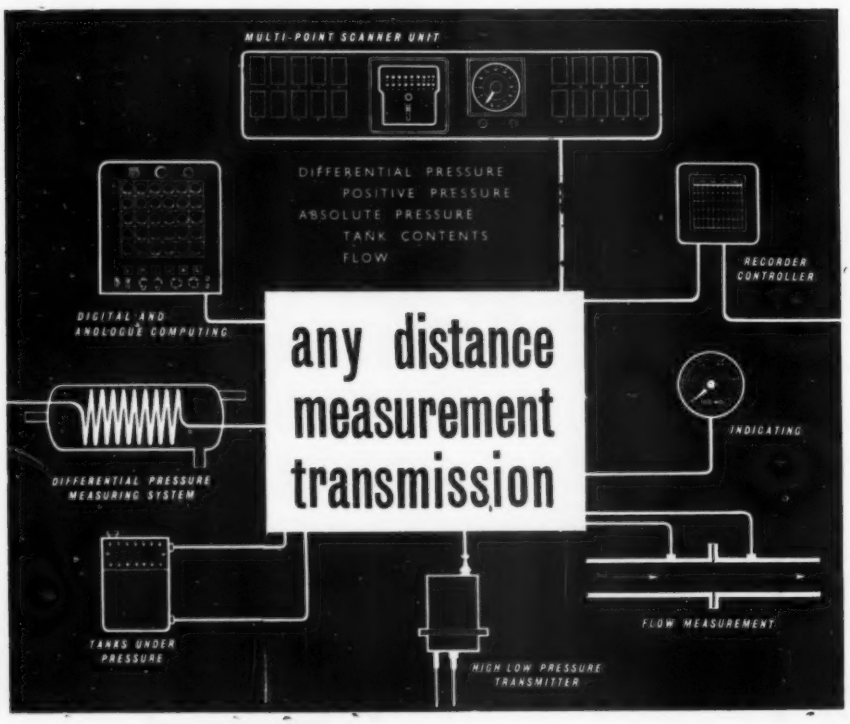

FEATURES OF THE 'REDIFF' PRESSURE GAUGE

★ Measurements from 0 to 1 inch of water gauge full scale deflection.

★ High Static Pressures gradually or instantaneously.

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★ Models made of MONEL available.

★ Capable of withstanding sudden pressures up to 4,000 p.s.i. and temperature up to 250°c.

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Il est souvent difficile au client publicitaire d'indiquer dans un espace restreint tous les détails de ses produits. Dans le cas où vous désireriez de plus amples renseignements à ce sujet, veuillez pointer le numéro approprié sur la carte ci-contre et envoyer cette dernière à NUCLEAR POWER.

AUSKUNFTSDIENST FÜR LESER

Es ist oft schwierig für Inserenten alle technischen Einzelheiten über ihre Produkte in einem begrenzten Platz zu bringen. Sollten Sie noch weitere Auskünfte wünschen, streichen Sie einfach die bestimmten Nummern auf der nebenstehenden Karte an, und senden Sie sie an NUCLEAR POWER.

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SERVICIO DE INFORMACIÓN PARA EL LECTOR

Se hace a menudo difícil para los anunciantes dar en un espacio limitado todos los detalles técnicos sobre sus productos. Si desea ulterior información, marque los números apropiados en la tarjeta opuesta y mándela a NUCLEAR POWER.

Информация для читателей

Часто бывает трудно рекламирующим лицам давать все технические подробности своей продукции в рекламе. Если Вам понадобятся добавочные сведения, то просто отметьте соответствующие номера на карточке на противоположной стороне и отправьте в NUCLEAR POWER.

讀者詢問服務

在廣告上以有限的地方來解釋一些專門技術，及它們的功能，的確是有受限制的困難。若讀者欲要知道一些詳細的情形就請將對頁的表格，取一號下來將閣下有疑問的項目，用筆勾一下即可，餘下能工經意即可。

讀者サービス

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5	28	51	74	97	120	143	166	189
6	29	52	75	98	121	144	167	190
7	30	53	76	99	122	145	168	191
8	31	54	77	100	123	146	169	192
9	32	55	78	101	124	147	170	193
10	33	56	79	102	125	148	171	194
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15	38	61	84	107	130	153	176	199
16	39	62	85	108	131	154	177	200
17	40	63	86	109	132	155	178	201
18	41	64	87	110	133	156	179	202
19	42	65	88	111	134	157	180	203
20	43	66	89	112	135	158	181	204
21	44	67	90	113	136	159	182	205
22	45	68	91	114	137	160	183	206
23	46	69	92	115	138	161	184	207

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209	215	221	227	233	239	245	251	257
210	216	222	228	234	240	246	252	258
211	217	223	229	235	241	247	253	259
212	218	224	230	236	242	248	254	260
213	219	225	231	237	243	249	255	261

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262	264	266	268	270	272	274	276	278
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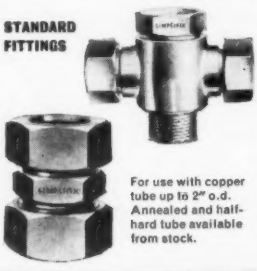

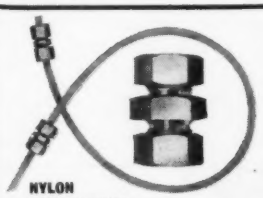
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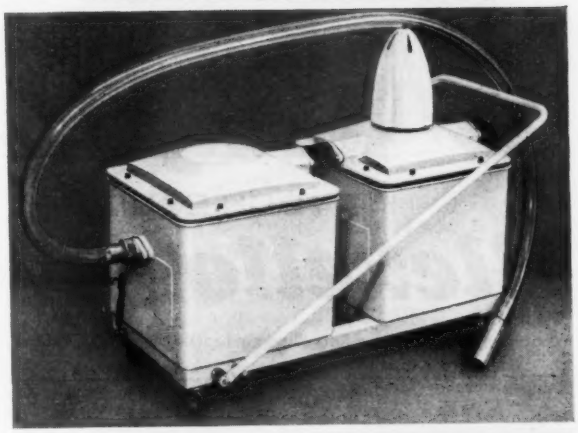

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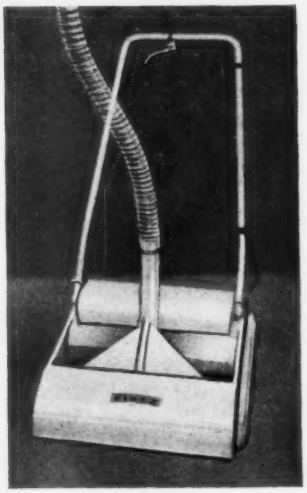
"A floor scarifier for removal and collection of hazardous deposits. Adapted for use in conjunction with user's extractor plant." **CODE 92**



and manufacturers of specialised floor cleaning equipment for the Nuclear Power Industry

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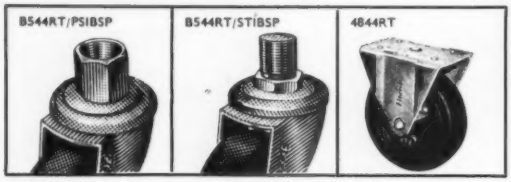

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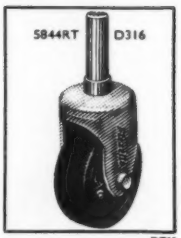

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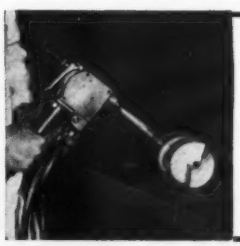

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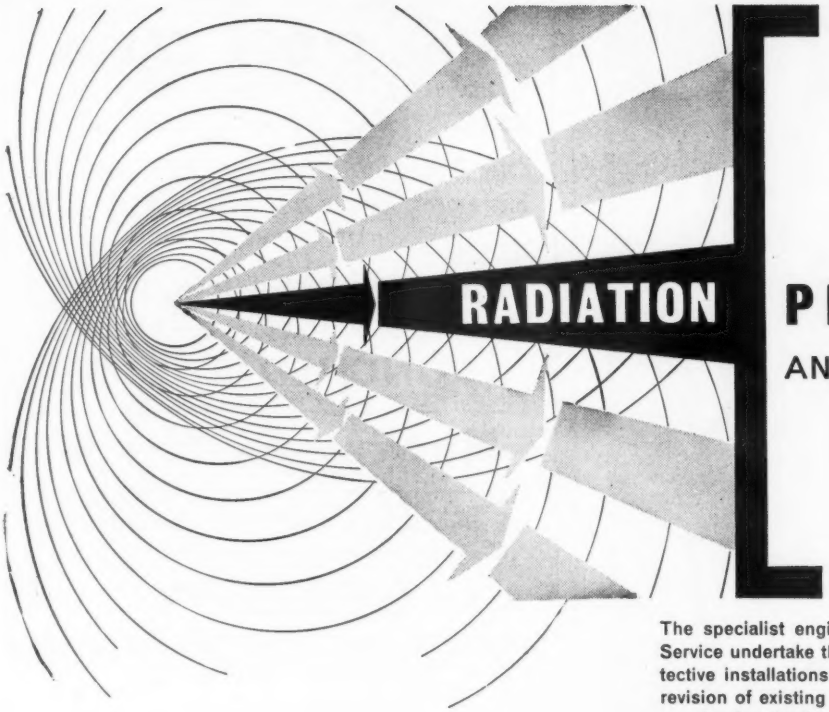

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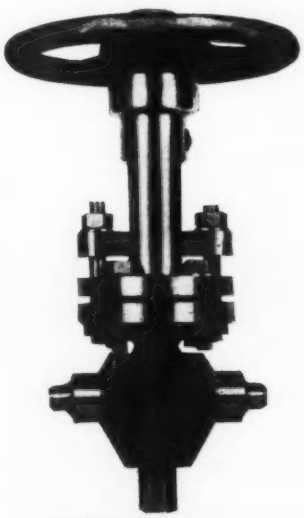

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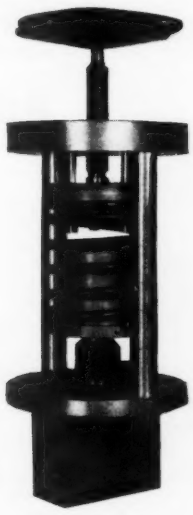
Designers and manufacturers of precision equipment for the control of gases and fluids at high temperatures and pressures



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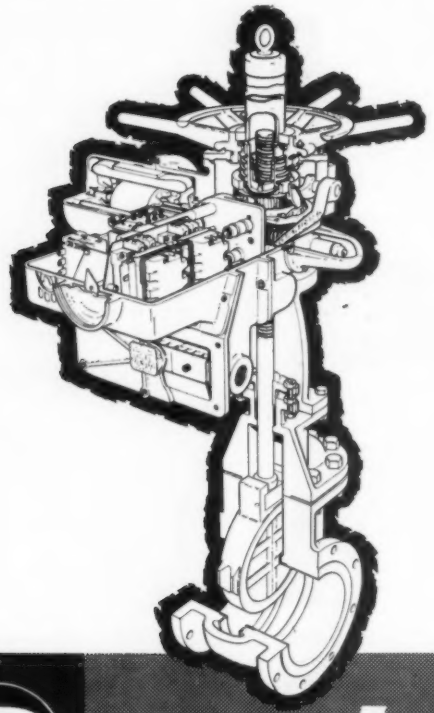

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Name any big company in a valve-using industry and it is almost certain that you have named a Rotork customer.

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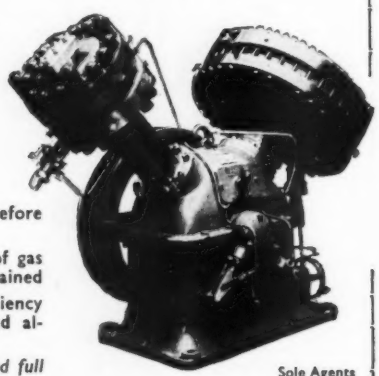
ALL PRESSURES UP TO 30,000 P.S.I.

. . . for pure dangerous or corrosive gases and liquids



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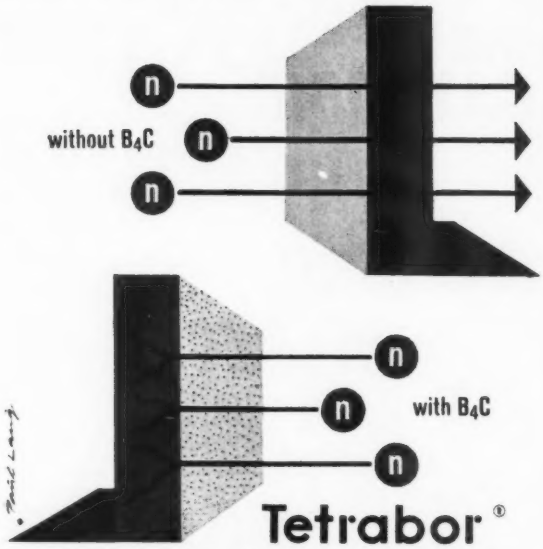

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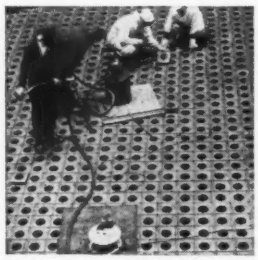

Simplex model removing dust within No. 1 reactor at Bradwell, on 25th June, 1960.
Photo by kind permission of The Nuclear Power Group, Bradwell and the Central Electricity Generating Board.

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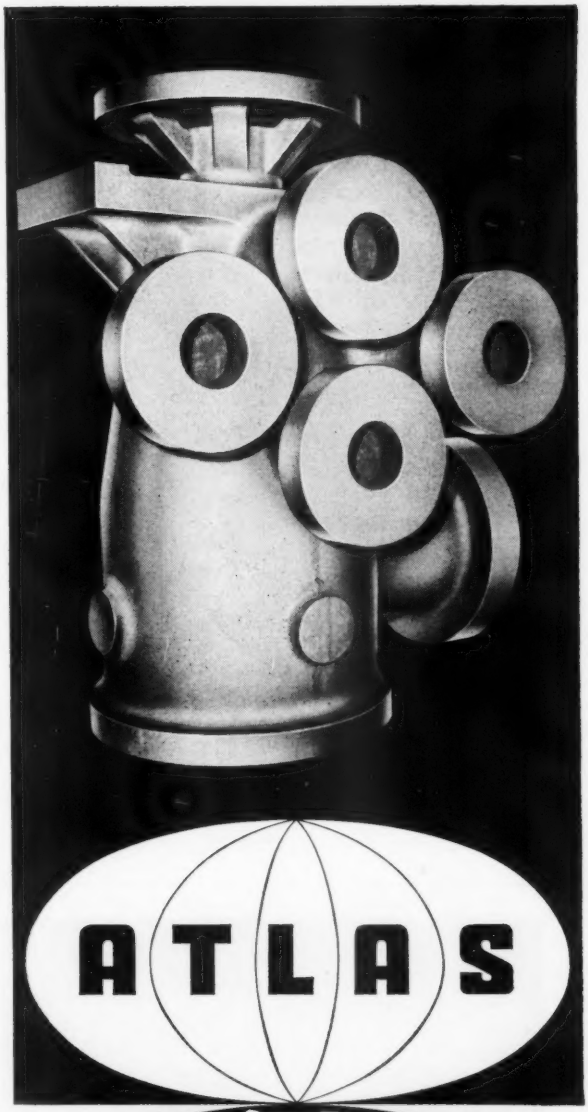

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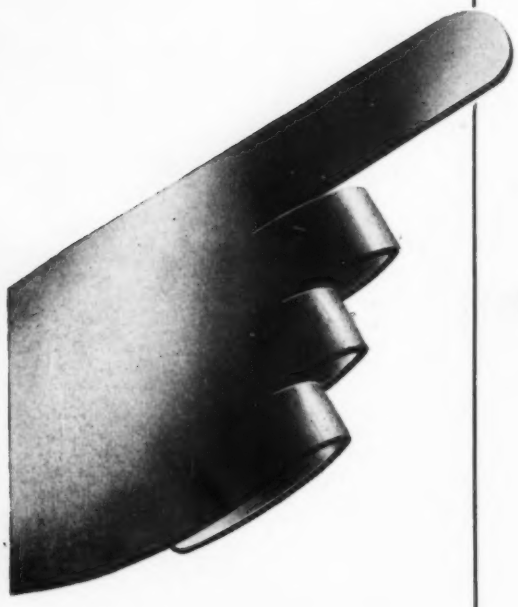

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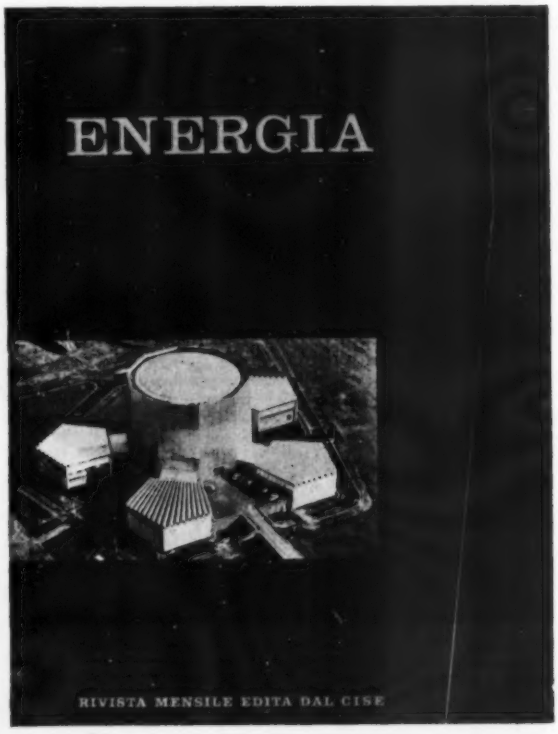

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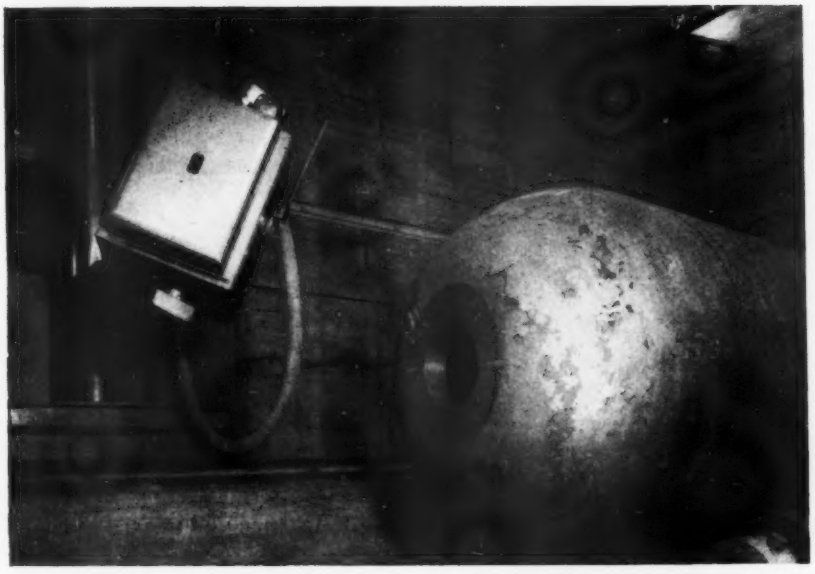

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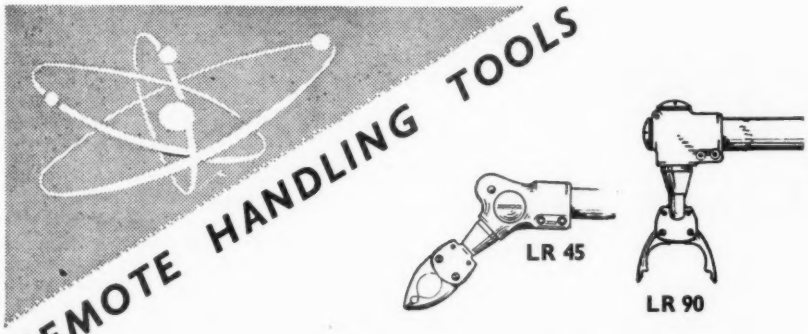

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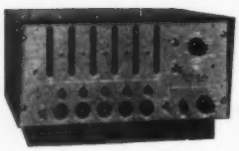

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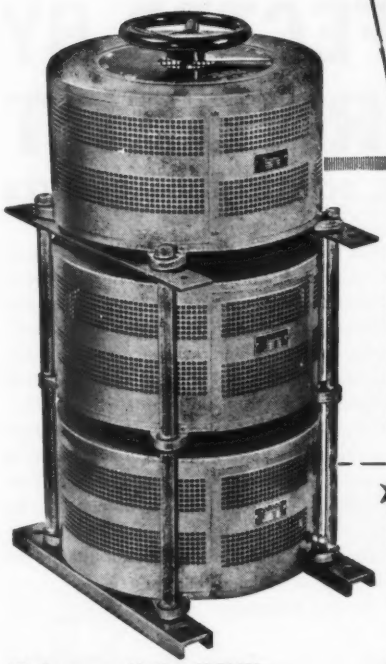

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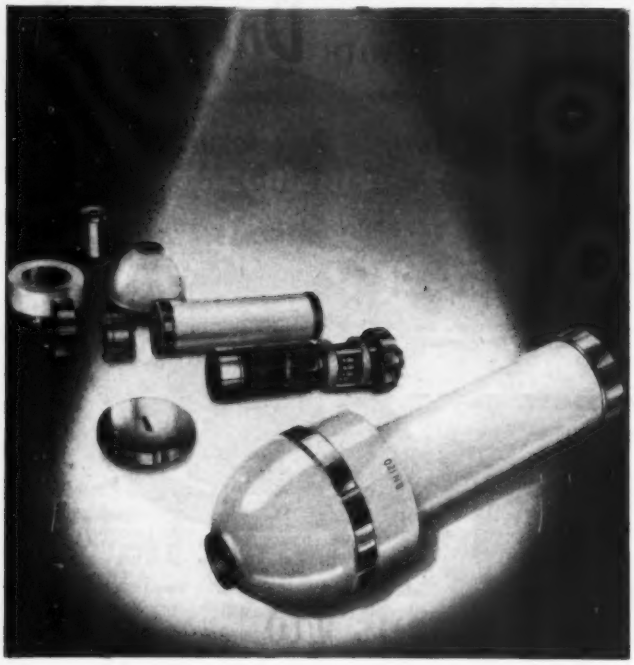

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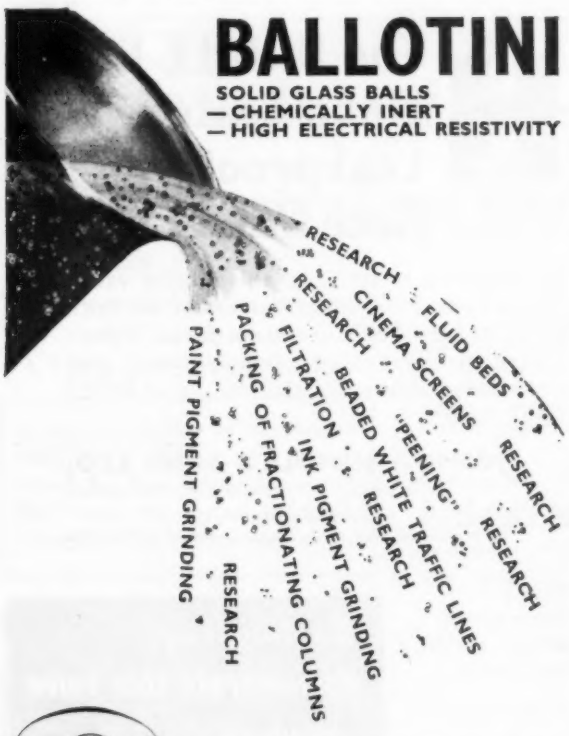

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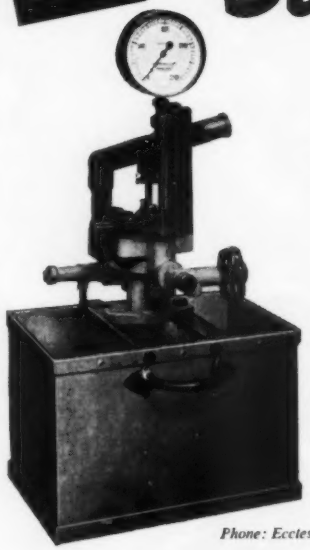

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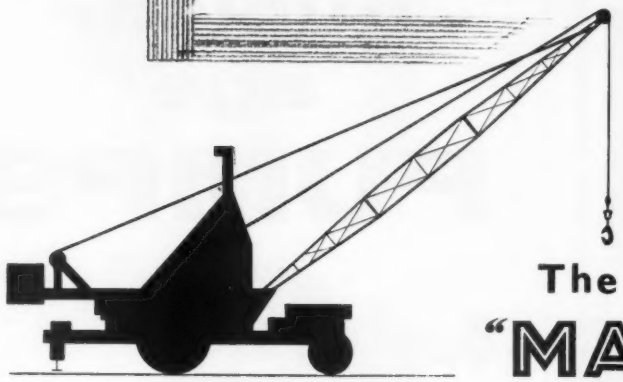

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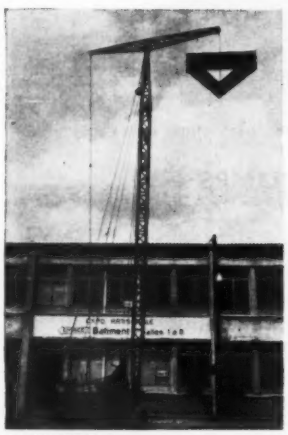

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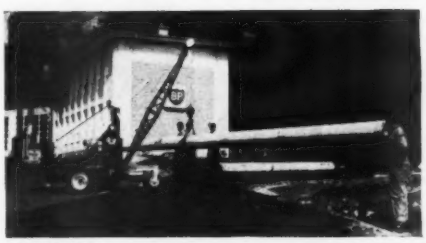

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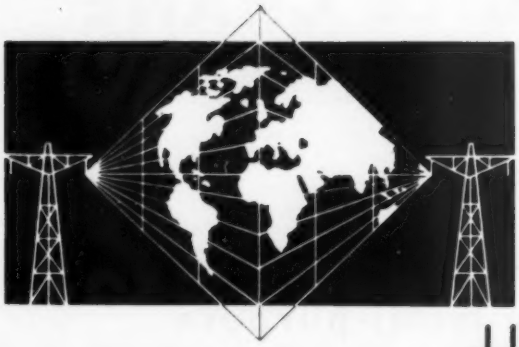

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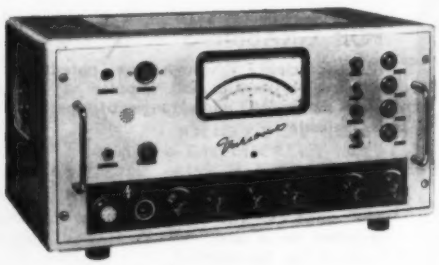

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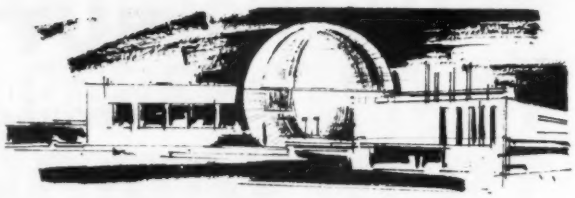
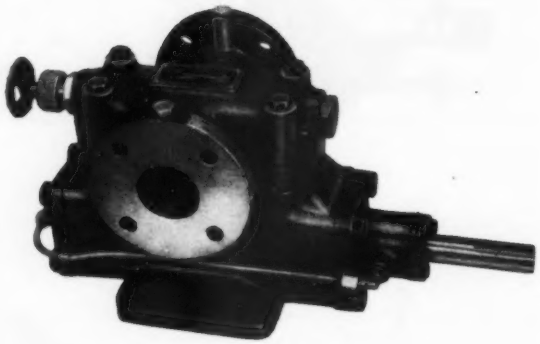


nuclear age PUMPS



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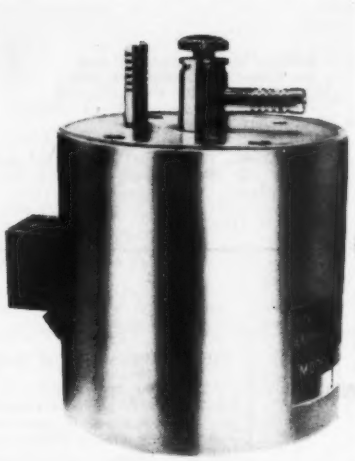

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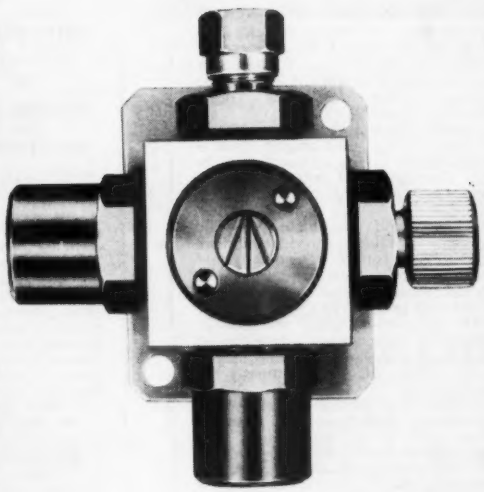

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Applications are invited for the abovementioned posts. The Department is interested in various research fields, including angular correlation of nuclear radiations; polarised nuclear reactions; ion optics; time-of-flight neutrons. Preference would be given, other things being equal, to candidates with theoretical or experimental knowledge of any of the above fields, or similar fields. The Department has a 600 KeV Cockcroft-Walton accelerator, which will later be supplemented by a Van de Graaf accelerator (2-2.5 MeV) at present being shipped out from the United Kingdom. There are very good and rapidly increasing facilities and opportunities for experimental or theoretical nuclear research.

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Applications close, in New Zealand and London, on 15th July, 1961.

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Applications are invited for the post of LECTURER IN ENGINEERING (Mechanical). Preference will be given to candidates with a major interest in Applied Mechanics, especially Theory of Machines, Stress Analysis and Properties of Materials, or Applied Thermodynamics. An interest in Mechanical Design would be an advantage. University regulations permit teaching staff to read for the degree of M.Sc. and Ph.D. The salary scale £1,050 to £1,850 per annum. Membership of F.S.S.U. and Children's Allowance Scheme. Initial salary according to qualifications and experience. Applications should be sent not later than July 8th, 1961, to the Registrar, The University, Manchester, 13, from whom further particulars and forms of application may be obtained. Applications by airmail letter, in the first instance, will be considered from overseas candidates.

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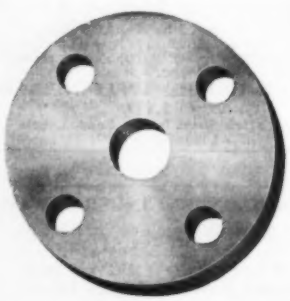

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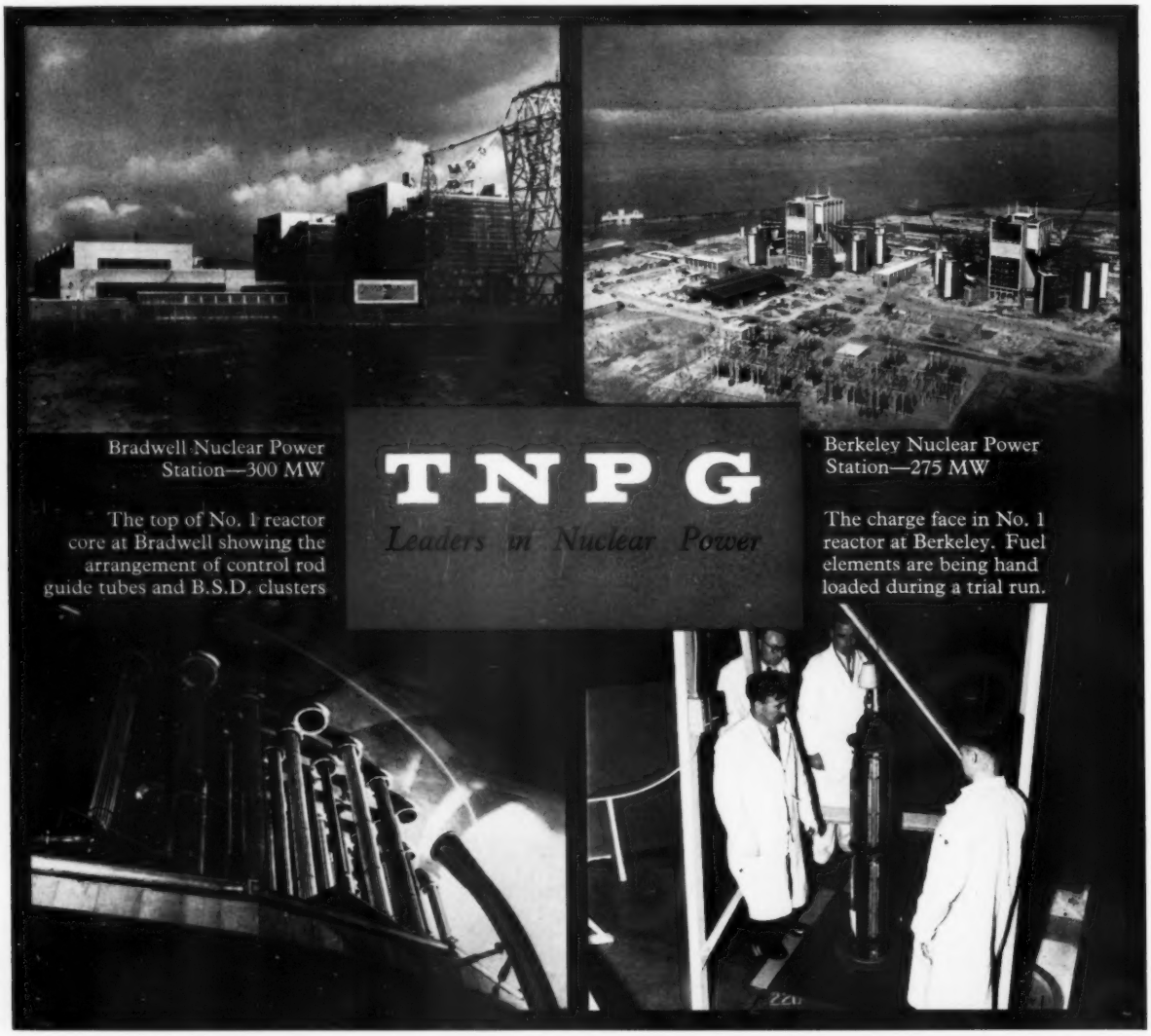
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